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UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/638-15

College on Medical Physics:
Imaging and Radiation Protection

31 August - 18 September 1992

Use of a Programmable Image Processing System in Image Quality Assessment

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Laboratory session

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1- INTRODUCTION

Bad performances of electromedical equipment due to improper (or even non-existing) periodic quality control is a common problem in many hospitals. In particular, high-tech and expensive equipment, such as MR scanners, CT scanners, DSA, etc., need frequent image quality assessments to prove that the diagnostic power has not decreased.

The Information and Evaluation Center on Biomedical Equipment (CIVAB), has been working in this field since 1987. Assessing programs Were gotten ahead on diagnostic equipment (Real time US scanners, CT scanners, PACS), automatic clinical analyzers and instruments for therapy (lithotripsers, surgical lasers).

On behalf of the Italian Department of Health, in 1991/92, CIVAB has produced an original protocol for image quality assessment on MR scanners, culturally originated from the European COMAC-BME concerted action. The protocol has been tested on 8 different models of scanners (representing 90 % of the Italian market) and the results have been summarized in a detailed final report.

The following set of image quality parameters has been measured on each scanner:

1. Image uniformity
2. Signal to noise ratio
3. Uniformity of signal to noise ratio
4. Artifacts (ghosting level)
5. Geometric distortion
6. Slice width
7. Spatial resolution
8. Contrast to noise ratio
9. T1 and T2 accuracy

Even if the diagnostic meaning of T1 and T2 relaxation times is still matter of opinion, it is out of doubt that the accuracy of the measure is one of the most sensitive parameters referring to the calibration of the scanner. Less than 50% of the examined scanner have shown an accuracy within 10 % of the theoretical values and so are out of the acceptability range. Therefore, it is evident that much more work is to be done if the goal is to reach a level of optimum performances.

The final results show clearly that a program of periodic quality controls can increase the diagnostic power and the efficiency of the equipment.

We do believe that effective cooperation between the maintenance and the quality control team is the right way to improve the service.

2. MAIN GOAL OF THE SESSION

Image quality assessment needs expensive equipment with powerful computers and software... It is WRONG! It is possible to do a good job with a set of test objects usually provided by the manufacturer of Your scanner, a PC, a Matrox board and a C, or PASCAL or FORTRAN compiler. The basic software provided with a Matrox card is enough for simple image processing and quality assessment. In the following chapters it will be shown how to perform a calculation of signal uniformity on digital images acquired with a MR scanner and using a flat field phantom.

3. DIGITAL IMAGES, PIXELS & MATRICES

The enormous diagnostic utility derived from the recent great technical innovations which have issued from nuclear medicine, image-intensified video fluoroscopy, computed tomography, magnetic resonance imaging, etc., have triggered vast amounts of activity to avail all of diagnostic medicine with the powers derived from computerization.

The presence of computers has led to an increasing diversity in the types of studies performed in departments and has allowed quantification of the data recorded during an examination. In addition, digital images acquired by the computer system can be manipulated to provide the optimal diagnostic view for the physician.

The difference between "image" and "digital image" can be easily understood reading the following example regarding X rays.

Radiography is a form of physical diagnosis in which X rays are used to obtain medically useful information about a patient. A beam of X rays is passed through the patient. The differential absorption of radiation by different tissues modulates this beam. The transmitted beam is detected by the emulsion and a film blackening is produced. In this process no calculations have been performed. The final image is the result of a chemical reaction.

In Computed Tomography a beam of X rays is passed through the patient. The differential absorption of radiation by different tissues modulates this beam. The transmitted beam is detected, the intensity is measured and the value is used by computer for further heavy calculations. The final result of these heavy calculations is a matrix of numbers (see Fig. 1)

0	170	200	128	170	255	128	200
128	170	0	255	200	0	170	128
0	255	128	0	255	128	200	0
255	128	128	255	128	0	255	128
0	200	170	170	255	200	170	0
255	200	255	0	128	200	128	170
128	0	255	0	170	0	255	128
0	0	128	128	200	200	170	255

Fig. 1

The brightness of each point of the final image can be artificially determined from these matrix numbers.

For example, it is possible to give the color white to the value 255 and the color black t the value 0. (see Fig. 2).In this way We have obtained a first example of digital imaging.

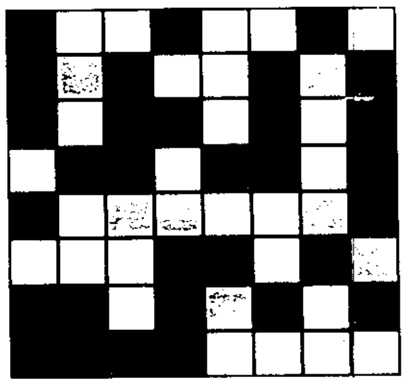

Fig. 2

It is important to outline that every digital image displayed on a screen or printed on a film is just the appearance of a finite, numerical matrix and that the number of points in the digital image is given by the number of values in the numerical matrix.

Of course, each "point" in the digital image has a finite area. This minimum element of area is called "pixel". Due to the biunique correspondence, it is usual to call "pixel" as the area element in the digital image as well the element in the numeric matrix. Moreover it is usual to call image also the numeric matrix.

4. IMAGE FORMATS

Digital images are files produced by computers. Files can be stored on many different mass storage memories. The most common are the following (in brackets a standard capacity in Mega Bytes):

- Magnetic disks (100 MB)
- Magnetic tapes (100 MB)
- Streamer tapes (100 MB)
- Floppy disks (1 MB)
- Optical disks (1 GB)

Should I be able to overcome all the hardware problems, can I easily read images stored in memory? Probably no. There are also some software problems:

1. -Each disk or tape can be formatted in different ways depending by the operating system of the main computer and by the choices of the operator.
2. -Each manufacturer usually adds to the images some headers, that is files containing examinations, patient and hospital information.
3. -Sometimes images can be compressed. If You want to read these images, You need to know the compression algorithm.

In 1985 ACR-NEMA proposed a standard (Fig. 3) for image transmission and archiving. Unluckily, this standard is present just in some systems as an option.

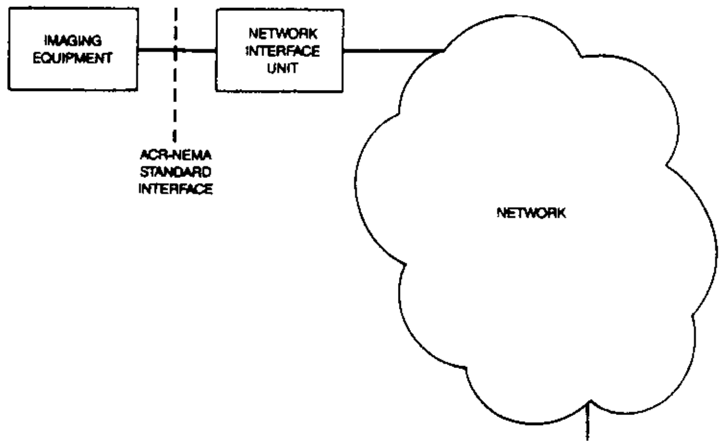

Fig. 3

5. - THE MEANING OF LOOK-UP TABLE (LUT)

5.1 - Black and White

In chapter 3, You can find the sentence: "it is possible to give the color white to the value 255 and the color black to the value 0". In this way You have roughly defined a Look-up table. A Look-up table is a relationship between numeric values and brightness.

For example, let us suppose that We need to view a matrix of numeric elements on a B/W screen. Each element is an integer value in the range 0 - 255.

It is possible to define a scale of brightness with 256 levels (from 0 to 255) in which white is the highest level (level 255), and black is the lowest level (level 0). We can define a look-up table in the following way:

INTEGER VALUE	BRIGHTNESS LEVEL
0	0 (black)
1	1(dark gray)
2	2
3	3
4	4
5	5
6	6
...	...
N	N
...	...
255	255 (white)

The brightness is univocally determined by the previous table. But We can define a look-up table also in the following way:

INTEGER VALUE	BRIGHTNESS LEVEL
0	255 (white)
1	254 (light gray)
2	253
3	252
4	251
5	250
6	249
...	...
N	255 - N
...	...
255	0 (black)

In which higher values are associated to darker grays. This one is an inverted gray look-up table.

It is important to outline that in digital imaging the integer value of the matrix element is related to the physical phenomenon (X rays attenuation, energy absorption, etc.) while the brightness is artificially given by the operator.

5.2 - Colors

It is possible to define three primary colors (usually red, green and blue). A proper mixture of these colors can produce every hue You need.

In Matrox boards and in many other similar graphic boards, You can define three different look-up tables, one for each primary color.

The same considerations done in the previous paragraph for gray levels can be repeated for each primary color. But now You need to define three look-up tables to obtain the right mixture of colors. For example, the following group of Look-up tables will produce an image with only red hue. In fact, the contributions of green and blue is zero.

INTEGER VALUE	RED LEVEL
0	0 (black)
1	1(dull red)
2	2
3	3
4	4
5	5
6	6
...	...
N	N
...	...
255	255 (fiery red)

INTEGER VALUE	GREEN LEVEL
0	0 (black)
1	0 (black)
2	0 (black)
3	0 (black)
4	0 (black)
5	0 (black)
6	0 (black)
...	...
N	0 (black)
...	...
255	0 (black)

INTEGER VALUE	BLUE LEVEL
0	0 (black)
1	0 (black)
2	0 (black)
3	0 (black)
4	0 (black)
5	0 (black)
6	0 (black)
...	...
N	0 (black)
...	...
255	0 (black)

The color of each pixel having numeric value N, is a mixture of the three primary colors. The contributions of blue and green is zero. So the color of the pixel is red with red level N.

If the contributions of the primary colors are the same, the result is a gray color. Therefore, it is possible to view a B/W image on a color monitor with a color graphic board.

NOTE: the mixture of 256 levels of red, green and blue can produce up to 16.7 millions colors. That is: 256 red levels X 256 green levels X 256 blue levels.

NOTE: due to hardware limitations of D/A converter, except for very expensive graphic boards, it is possible to display only 256 colors. That is, every pixel can potentially assume up to 16.7 millions colors, but after having defined Your look-up table, just 256 colors are available. If You want to display further colors, You need to change look-up table.

6. - IMAGE UNIFORMITY IN MR

6.1 - INTRODUCTION

If You want to do periodic controls on your equipment, You need to measure image quality parameters. Your assessments must be based on numbers. So, for example, You cannot say simply: "Yes, this image is uniform" or "No, this image is not uniform". You must be able to answer to the question: "How much uniform this image is?"

Let us consider a systems producing diagnostic images. Image uniformity refers to the ability of the imaging system to produce an identical signal response throughout the scanned volume when the object being imaged has homogeneous characteristics. A system with bad performances in uniformity will display a uniform tissue as a non uniform one. It is important to outline that this wrong information can strongly affect the final diagnosis.

Uniformity can be measured using a flat field test object: water phantom for CT scanners, uniform radioactivity slab for gamma cameras, paramagnetic ions solutions for MR scanners. Of course, the techniques on different diagnostic modalities are different.

6.2 - INTEGRAL UNIFORMITY AND UNIFORMITY MAP

Let us consider a MR image (Fig. 4) obtained using a standard acquisition protocol and a flat field phantom (TO1). We need to define a Measurement Region Of Interest: a centered, regular geometric area on the image.

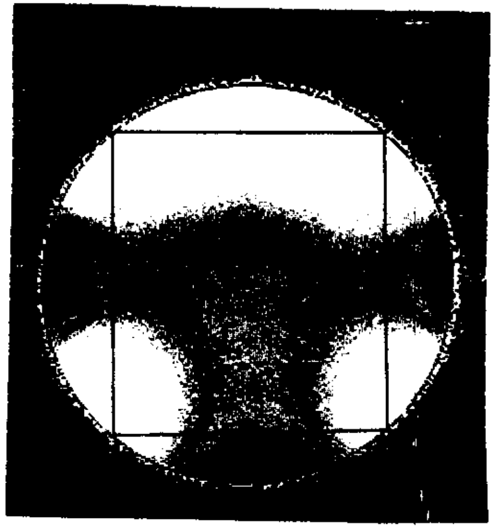

Fig. 4

In the Measurement Region Of Interest the maximum (Smax) and minimum (Smin) pixel values are determined. We define:

$$D = (S_{max} - S_{min}) / 2$$

$$S = (S_{max} + S_{min}) / 2$$

Integral Uniformity = $\pm$ 100 D/S

We can draw a histogram of the pixel values in the Measure Region Of Interest. The pixel value corresponding to the histogram peak is the Mean Value M. The uniformity map is readily created by the following procedure assigning a gray level to each pixel according to the magnitude by which the signal differs from M.

Pixels with signals more than 20% greater than the mean value will be white.

Pixels with signals less than 20% smaller than the mean value will be black.

Pixels with signal magnitudes differing by less than 10% from M will be assigned a neutral gray level.

Pixels with signals greater than M + 10%M but less than M + 20%M will be assigned the next lighter gray level.

Pixels with signals smaller than M - 10%M but greater than M - 20%M will be assigned the next darker gray level.

The final result is an image with only five gray levels. It is called UNIFORMITY MAP. The fraction of pixels in the central range is a good measure of uniformity since it is a bidimensional measure.

NOTE: due to a lack of standardization in image quality assessment, You will probably find many other definitions of uniformity. In this laboratory session, uniformity map has been introduced manly for didactic purposes.

References

1) D. G. Taylor et al.: NMR imaging in Theory and in practice; Phys. Med. Biol. 1988, Vol. 33, No 6, 635-670.

2) S. Hinshaw, A. H. Lent: An introduction to NMR imaging: from the Bloch equation to the imaging equation; Proceedings of the IEEE, Vol. 71, No 3, March 1983, 338-350.

3) I. Pinto, P. Giribona, D. Bravar: Valutazione delle prestazioni di tomografi NMR; atti del convegno "Controlli di qualita' ed ottimizzazione nell'impiego delle radiazioni in medicina", Brescia 1988.

4) R. L. Dixon, K. E. Ekstrand: The physics of proton IR; Med. Phys. Nov/Dec 1982, 807-818.

5) W. A. Edelstein et al.: The intrinsic SNR in NMR imaging; Magn. Res. in med. 1986, No 3, 604-618.

6) D. Shosa, L. Kaufman: Methods for evaluation of diagnostic imaging instrumentation;; Phys. Med. Biol. 1981, Vol. 26. No 1, 101-112.

7) J. J. E. In Den Kleef, J. J. M. Cuppen: RLSQ: T1, T2, and r calculations, combining ratios and least squares; Magn. Res. in med. 1987, No 5, 513-524.

8) D. E. Purdy (Siemens medical Systems): Draft: Characterization of special purpose coils for diagnostic magnetic resonance imagers; September 14, 1988.

9) W. A. Edelstein et al.: Signal, noise and contrast in NMR imaging; Journal of CAT, Vol. 7, No 3, 391-401.

10) M. W. Tsui et al.: Analysis of recorded image noise in nuclear medicine; Phys. Med. Biol., 1981, Vol. 26, No 5, 883-902.

11) O. Nalcioglu, Z. H. Cho: Limits to signal to noise improvement by FID averaging in NMR imaging; Phys. Med. Biol., 1984, Vol. 29, No 8, 969-978.

12) K. Faulkner, B. M. Moores: Analysis of x-ray computed tomography images using the noise power spectrum and autocorrelation function; Phys. Med. Biol., 1984, Vol. 29, No 11, 1343-1352.

13) M. F. Kijewski, P. F. Judy: The noise power spectrum of CT images; Phys. Med. Biol., 1987, Vol. 32, No 5, 565-575.

14) K. Faulkner, B. M. Moores: Comments on "The noise power spectrum of CT images"; Phys. Med. Biol., 1987, 1047-1049.

15) M. F. Kijewsky, P. F. Judy: Reply to "Comments on the noise power spectrum of CT images"; Phys. Med. Biol., 1987, 1049-1051.

16) R. A. Lerski et al.: Practical aspects of ghosting in resistive nuclear magnetic resonance imaging systems; Phys. Med. Biol., 1986, Vol. 31, No 7, 721-735.

17) D. W. McRobbie et al.: Investigation of slice characteristics in nuclear magnetic resonance imaging; Phys. Med. Biol., 1986, Vol. 31, No 6, 613-626.

18) M. Fuderer: The information content of MR images; IEEE Tr nsactions on medical imaging, Vol. 7, No 4, Dec. 1988, 368- 380.

19) M. D. Harpen: The density matrix formalism of nuclear relaxation: A review; Med. Phys., Vol. 15, No 4, Jul/Aug 1988.

20) Nema Draft: Determination of SNR in diagnostic magnetic resonance images.

21) Arnon Cohen: Biomedical Signal; CRC press, 1986.

22) A Li Evans: The ev ation of medical images; Medical Physics Handbooks; Page Bros Ltd., 1981.

23) L. W. Grossman et al.: Power spectrum Analysis of gamma camera image noise: stochastic and nonstochastic effects; Proceedings of SPIE, Vol. 454, Feb. 26-29, 1984 215-221.

24) J. S. Bendat, A. G. Piersol: Random data: Analysis and measurement procedures; Wiley-interscience, 1971.

25) V. Cappellini: Elaborazione numerica delle immagini; Boringhieri, 1985.

26) K. Doi et al.: MTF's and Wiener spectra of radiographic screen-film systems; Vol II; U. S. Department of health and human services; Mar. 1986.

27) P. G. Morris: Nuclear Magnetic Resonance Imaging in medicine and Biology; Oxford science publications, 1986.

28) M. R. Spiegel: Analisi di Fourier; Collana Schaum no. 26, 1976.

29) T. H. Newton, D. G. Potts et al.; Radiology of the skull and brain, technical aspects of computed tomography; The C. V. Mosby Company, 1981.

30) R. A. Lersky, D. W. McRobbie: MR quality assesment test objects; Diagnostic Sonar Ltd. 1987.

31) Philips medical systems: Principles of MR imaging; 1984.

32) R. A. Lersky et al.: Physical principles and clinical applications of NMR; Paradigm Print; 1985.

33) W. K. Pratt: Digital image processing; Wiley-interscience publication; 1978.

34) J. J. M. Cuppen et al.: Magnetic resonance fast fourier imaging; Med. Phys., Vol. 13, No 2, Mar/Apr 1986, 248-253.

35) R. F. Wagner, D. G. Brown: Unified SNR analysis of medical imaging system; Phys. Med. Biol., Vol. 30, No 6, 1985, 489-518.

36) D. J. Goodenough, K. E. Weaver: Phantoms for specifications and quality assurance of MR imaging scanners; Comp. Med. imag. graph., Vol. 12, No 4, 1988, 193-209.

37) S. Crestana et al.: Using a computed tomography miniscanner in soil science; Soil Science; Vol. 142, No 1, 1986, 56-61.

38) A. Spisni et al.: Use of test object TO5 to standardize relaxation measurements in MRI; Eurospin, No 19, Jun 1989, 31-54.

39) I. Pinto et al.: A preliminary assessment of contrast performances of MRI systems using TO5; Eurospin, No 19, Jun 1989, 55-66.

40) P. Mansfield, P. G. Morris: NMR Imaging in biomedicine; Academic Press, 1982.

LABORATORY SESSION

USE OF MATROX CARD

Note: use always lower case with the PIP interpreter

PRACTICE 1

HOW CAN I DISPLAY ON A RGB MONITOR IMAGES STORED ON A FLOPPY DISK?

1. I need to initialize the board:
inifmt 26c 1 1 0 1 0

2. I want to clear the screen
clear 0 7

3. I set a window (512 x 512 pixels) to display the image
setwindow 0 0 511 511

4. I read and display image imma.1 stored on floppy disk
winfrdisk 4096 a:imma.1 506a -1

Note: use always lower case with the PIP interpreter

PRACTICE 2

HOW CAN I DRAW A HISTOGRAM OF THE PIXEL DISTRIBUTION IN A REGION OF INTEREST (ROI)?

1. I want to use the color whose index in current LUT is 0:
setind 0

2. I want to draw a rectangle on the image to define the window:
rectangle 75 70 185 180

3. I want to set the window inside the rectangle:
setwindow 76 71 184 179

4. I want to calculate the histogram inside the previously selected window and to store data in the buffer:
histo 506a

5. I want to display the histogram
dhisto N 0 256 256 255 255 506a

Note: use always lower case with the PIP interpreter

PRACTICE 3

HOW CAN I DRAW A UNIFORMITY MAP?

1. I want to define the 1st level

```
scalin    0    0    147  0    506a
```

2. ... 2nd level ...

```
scalin    148  50   166  50   506a
```

3. ... 3rd level ...

```
scalin    167  120  202  120  506a
```

4. ... 4th level ...

```
scalin    203  190  221  190' 506a
```

5. ... 5th level ...

```
scalin    223  255  255  255  506a
```

6. I want to use the same LUT for each primary color

```
lutd 4    1    0    255  506a
lutd 4    2    0    255  506a
lutd 4    3    0    255  506a
```

7. I want to select the current LUT map

```
lutm 4
```