Measure of Image Quality

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My career in medical physics and engineering started at Mosrentgen, Inc., the largest company of the former Soviet Union produced X-ray equipment. It was not my choice but my fate and I never regretted it. Evaluation of image quality on the monitors of our expensive diagnostic machines equipped with X-ray image intensifiers was then one of the most important and annoying problems. Researchers and developers tried to create the system of physical parameters characterizing image quality. However, our customers and radiologists from medical centers were not satisfied with the measurements and did not believe that the correlation between clinical diagnostic value of an image and its physical characteristics was good. It became clear that an observer or physician interpreting the image is an unalienable part of the imaging chain. The decision about the influence of the measured parameters on image clinical value is made by people therefore so called objective instrumental method are also subjective. Besides, not all information is important or can be received by physician. For example, an image on a simple fluoroscopic screen contains more information than on the output screen of an image intensifier under the same conditions, but because of very low brightness of the fluoroscopic screen a lot of information is inaccessible for an observer.

The ability of imaging system to detect internal structure elements of small size and little contract is usually evaluated visually with pathology simulators inserted into tissue equivalent phantoms. The response of the observer who knows beforehand the fixed locations of the simulators or test elements is influenced by underlying bias. Besides, this subjective method does not allow to measure uncertainties arising from image noise or verify the accuracy of observer's estimations.

The excellent ICRU report 54"Medical Image - The Assessment of Image Quality" was published 13 years ago. This report is devoted to "statistical decision theory within which imaging system performance may be measured, optimized and compared." The authors of the report declared that the only method allowing performance to be separated from observer's bias is the application of receiver operating characteristic (ROC) curve methodology." ROC analysis was introduced into medical diagnostics more than 40 years ago. There are hundred of scientific articles describing advantages of this method. However, the statistical approach and ROC analysis are still very far from routine clinical practice because of long measurements and complicated calculations.

At Mosrentgen and Moscow Radiological Institute we developed statistical phantoms and method that combines simplicity of visual evaluation with unbiased, reliable, and reproducible quantitative results. Our goal was not to exclude a human visual analyzer but to eliminate human bias. An observer had to estimate the likelihood of existence of pathology simulators in various region of interest. The disposition of the simulators was not known to the observer beforehand and could be changed arbitrary. After comparing the results of estimation with real location of simulators, the probabilities of true-positive (sensitivity), true-negative (specificity) and true (accuracy) answers as well as the inclination of the observer to over-diagnostic or misses were calculated**. The smallest size of the test element or pathology simulator in phantom detectable in an X-ray image with the certain probability (standard deviation) was assumed as a measure of image quality**.

The statistical method was intensively used for acceptance testing of X-ray diagnostic systems and for quality assurance purposes in our company and many medical centers and then was included into Russian and some other national standards. Later when I left Russia and worked in Israel we created special ALVIM phantoms for radiography, mammography and fluoroscopy with changeable disposition of test elements (pathology simulators), so that an observer could not know their locations during the experiment. Nuclear Associates, Inc., our major distributor sold a few dozens of ALVIM statistical phantoms (www.seamp.org/materials/phantoms.pdf) and asked me to apply for a patent (www.seamp.org/materials/patent.pdf) and write an article that was published in "Medical Physics" journal (www.seamp.org/materials/medphys.pdf).

Set of ALVIM Statistical Phantoms

ALVIM Fluoroscopic Statistical Phantom

In Internet you can find a lot of other scientific papers in different languages devoted to ALVIM phantoms and this statistical method. Described techniques are, probably, still tedious and inconvenient for evaluating analogous imaging devices in daily clinical practice but the method can be very simple and powerful when applying to digital systems. Prof. John Cameron, the founder of Gammex RMI and Medical Physics Publishing, encouraged me to create software that could automatically change the disposition of test elements and perform the calculation using all might of the ROC analysis. This software was developed by George Davydenko, Canadian physicist and programmer emigrated from Ukraine with active participation of Dr. Mark Smekhov, Director of Israeli branch of SEAMP. The entire test can be completed within just a couple minutes. The results of our work were reported at SPIE symposium "Medical Imaging 2002" and published in the proceedings (www.seamp.org/materials/spie.pdf). George Davydenko also developed a demo version of this software (click here), that was demonstrated at SCAR symposium in Cleveland, OH (www.seamp.org/materials/demo.pps).

The statistical approach is particularly useful in Image Guided Radiation Therapy for assessment of noisy portal image quality, CBCT, tomotherapy MVCT, fused PET/CT and CT/MR images. Different modalities require applications of various phantoms made of different materials but the measure of image quality, statistical principle and processing method are the same. It is possible to calculate the average size of test element or pathology that can be detected with given probability on the base of measured characteristics of human visual analyzer and the imaging system. However, there are a lot of questions that require collaborative work of researchers, clinical physicists and physicians, and experts in medical imaging and radiation therapy.

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