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Determining an image noise defining parameter in clinical CT studies. A feasibility study.

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Abstract: An important aim of research in the field of image quality assessment in clinical CT is the drive to eliminate time and cost inefficient human observers or the dependence on technical phantoms. Current methods cannot provide to these needs. However, we provide a form of measurement of image noise that is independent of either, can be applied on clinical CT studies containing anatomical structures and is proportional to common forms of measurement. Experimental results indicate good reproducibility, excellent correlation with image noise and acquisition dose and potential for further development towards automatic application.

I. Introduction

In clinical computed tomography (CT) image quality and perception are the pillars of successful and reliable diagnosis. Traditionally image quality is defined and measured by sharpness of the image and the amount of noise in the image, while perceptional quality – in clinical CT – relies on human observers. While giving an accurate estimate of image quality, human observers are cost and time inefficient. Recent studies introduced mathematical model observers (MO). Model observers employ mathematical functions and filters to mimic certain characteristics of the human visual system; thus, they are designed to act as a surrogate observer of medical images. Used in alternative forced choice experiments they produce a measure of detectability of lesions in the evaluated image [1, 4]. While MO might eliminate the need for human observers in task-based image quality assessment they rely on many images in set up and the usage of technical phantoms. Because of the dependence on technical phantoms they can only provide a surrogate and not a direct assessment of clinical image quality [1, 4]. The evaluation of clinical image quality is of major importance for quality control and optimization of exam protocols, concluding in the possibility to significantly reduce the collective patient dose. To the best of this studies knowledge there currently is no other option to evaluate clinical image quality than by human observer. This study aims to evaluate the possibility to extract an image noise defining parameter in heterogenous CT images – containing realistic anatomy – by normalizing images and analyzing the resulting histograms, thus providing potential to further develop an automatic noise estimation independent of technical phantoms and human observers. Our goal is to automatically estimate image quality directly out of individual patient exams.

II. Material and methods

By applying local mean subtraction and divisive normalization, an image of locally normalized luminances can be produced [2, 3].

$$\hat{I} = \frac{I(i,j) - \mu(i,j)}{\sigma(i,j) + C} \tag{1}$$

Where $i \in 1,2\ldots, M$, $j \in 1,2\ldots, N$ are spatial indices, C a constant to prevent division by 0 in homogenous areas of the image and

$$\mu(i,j) = \sum_{k=-K}^{K} \sum_{l=-L}^{L} \omega_{k,l} I_{k,l}(i,j) \tag{2}$$

$$\sigma(i,j) = \sqrt{\sum_{k=-K}^{K} \sum_{l=-L}^{L} \omega_{k,l} \left(I_{k,l}(i,j) - \mu(i,j)\right)^2} \tag{3}$$

where $\omega_{k,l}|k = -K,\ldots, K, l = -L,\ldots, L$ is a 2D circularly-symmetric Gaussian weighting function sampled out to 3 standard deviations and rescaled to unit volume.

Image histograms of locally normalized luminances follow a gaussian-like distribution, which can be approximated by a generalized gaussian distribution (GGD).

$$f(x;\alpha,\sigma^2) = \frac{\alpha}{2\beta\Gamma(1/\alpha)} \exp\left(-\left(\frac{|x|}{\beta}\right)^{\alpha}\right) \tag{4}$$

where

$$\beta = \sigma\sqrt{\frac{\Gamma(1/\alpha)}{\Gamma(3/\alpha)}} \tag{5}$$

and $\Gamma(\cdot)$ is the gamma function.

These histograms are distinctively influenced by image quality defining parameters, such as the amount of noise present in the image. Noise generally reduces the weight of the tail of the GGD, resulting in wider histograms, thus a larger variance σ^2 which can be quantified by β.

In this study, noise and β were determined independently and a proportionality between both was evaluated. The image database to be evaluated consists of a CT study of an anthropomorphic head phantom at 10 different dose/noise levels and otherwise identical image acquisition parameters. Images acquired on a Definition® CT-Scanner (Siemens, Erlangen, Bavaria, Germany) and reconstructed with filtered back projection.

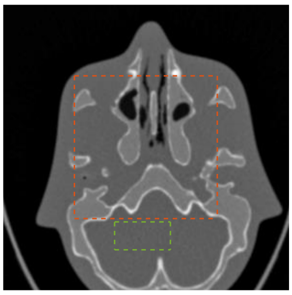

Figure 1: CT-Slice image of the anthropomorphic phantom. Red: image area to extract β. Green: Area of noise estimation.

III. Results and discussion

CT – images at 10 noise levels were normalized, the resulting histograms approximated with a GGD and β extracted as the defining parameter of the distributions spread. β was displayed as a function of the noise level in the respective image (Fig. 1). We were able to fit the trend as a power function with feasible accuracy of $R^2 = 0.97$. With R^2 the coefficient of determination. Error bars are included as the standard deviation of β in three consecutive slices of our dataset. With standard deviations better than 0.02 we achieve excellent reproducibility. By these results we show that the dependence of β is in direct correlation with the noise level in our CT – images.

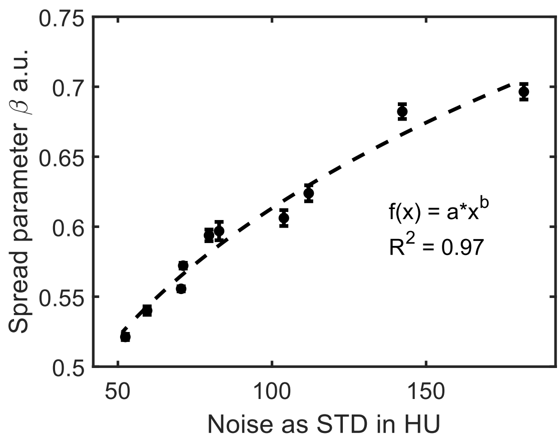

Figure 2: Distribution's spread defining parameter β as a function of the noise level of the image as the standard deviation (STD) in HU.

We further show that β is in excellent correlation with the acquisition dose of our images (Fig. 2). This trend can be fitted with a power function in feasible accuracy of $R^2 = 0.98$.

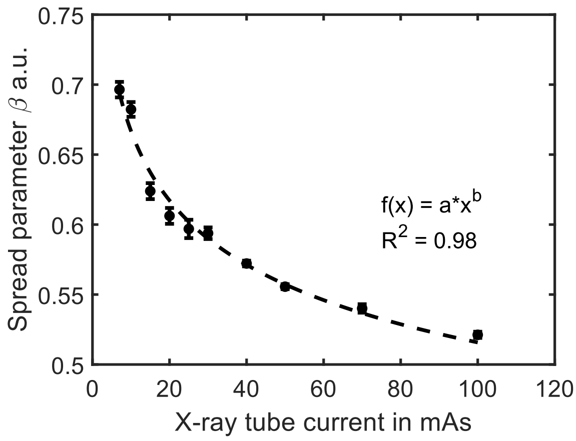

Figure 3: β as a function of the x-ray tube current value in mAs.

With these results we were able to show that it is feasible to extract a parameter (β) from the distribution of normalized luminance coefficients in an area of the CT – image that includes anatomical structures. Further we demonstrate that this parameter is in excellent correlation with image noise in an independent and homogenous area of the same image and at last that β correlates with the x-ray tube current. Thus, providing a form of measurement that is proportional to common noise measurements but applicable to clinical CT studies containing patient anatomy.

IV. Conclusions

We were able to show that a parameter proportional to image noise can be extracted from heterogenous images containing anatomic structures, thus providing potential to further develop a tool to automatically estimate image noise in patient individual clinical CT studies without the need of technical phantoms or human observers.

Author's statement

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