Evaluation of Physical Properties on Ink-jet Printing for Medical Imaging

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Abstract

The goal of this research is to construct the X-ray image output system using ink-jet printer. In order to apply the ink-jet image to medical imaging such as X-ray images, the sufficient quality of ink-jet images is required. In the first step, we measure the tone reproduction characteristics, Contrast Transfer Function (CTF), and Wiener Spectrum (WS) of ink-jet image and conventional silver halide film. The second step is the subjective evaluation performed by medical doctors using medical images printed on silver halide films and ink-jet images. We evaluate the reliability of ink-jet output system based on the results from the receiver operating characteristic (ROC) analysis.

Introduction

Silver halide film has been used for X-ray output system for long years. This output system, however, has disadvantages of high cost in output, storage, multiplication, and so on. To overcome such problems, soft-copy diagnosis is done on a monochrome cathode ray tube (CRT) display or on a liquid crystal display (LCD). Although from these studies, soft-copy diagnosis is enough effective for medical treatment[1, 2], such dedicated display devices are still very expensive so that it takes for long years to replace completely from hard copy to soft-copy diagnosis.

In recent years, the quality of ink-jet printing images has been rapidly improved and both the hardware cost and running cost are very economical in comparison with the conventional devices. The studies on print and image quality of ink-jet printing are widely done[3, 4, 5, 6]. Therefore we consider that ink-jet images have the capacity to use for medical images instead of conventional silver halide film.

In this study, we evaluate the ink-jet image physically and subjectively applying to medical imaging such as X-ray images. In the physical evaluation, we measure the tone reproduction characteristics, Contrast Transfer Function (CTF), and Wiener Spectrum (WS) of the ink-jet image and the conventional silver halide film. The subjective evaluation is performed by medical doctors using medical images printed on silver halide films and ink-jet images. We evaluate the reliability of the ink-jet output system based on the results from the human visual evaluation of the sensitivity by using the burger phantom and the receiver operating characteristic (ROC) analysis.

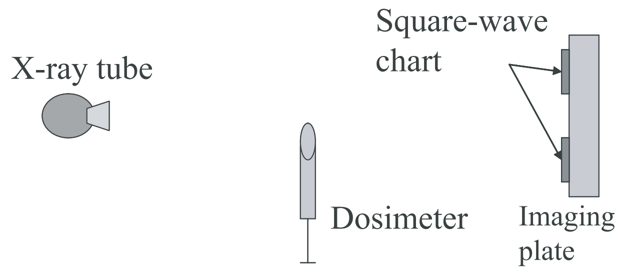


Figure 1: *Our X-ray imaging geometry*

Printing system

To evaluate the physical property on the ink-jet printing and the conventional silver halide film for medical Imaging, we examine the X-ray imaging instead of using digital chart data as the input. The geometry of our examination is shown in Fig.1, where the X-ray tube is KXO-80F by Toshiba Corporation, the CR system is FCR5000 by FujiFilm Medical Co.,Ltd., the dosimeter is by Radical and the square wave chart is Type7 for MTF measurement by Kyokko Co.,Ltd. We give the tube voltage as 70kV, the resolution of the CR system is 100μm pitch. The square wave chart is placed on the imaging plate with 1 degree inclination.

The diagram of our overall medical printing systems is shown in Fig.2. The imaging data taken by the above CR system run through the DICOM gateway, and are distributed to the dry imager (FM-DPL by FujiFilm Medical Co.,Ltd., 254dpi) and the monochrome ink-jet printer (CXJ-3000 by Canon Inc.) respectively. This ink-jet printer is customized for medical imaging because it has 5 level mono- chrome inks and it can print 4096 gray level pixels with 600dpi by using area coverage modulation.

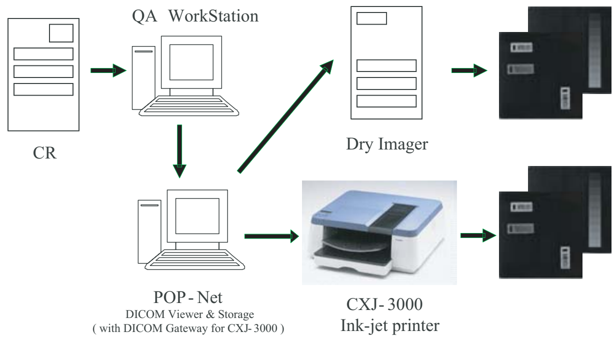


Figure 2: *The diagram of our overall medical printing systems*

Physical evaluation

We perform the physical evaluation by measuring the tone reproduction curve, CTF and Wiener Spectrum. For the physical evaluation, we use spot densitometer (PDA-65 by Konika Minolta) and micro densitometer (PDM-7 by Konika Minolta).

In Fig.3, the lower and upper graphs represent the tone reproduction characteristics of the CR system and printing systems, respectively. Both horizontal axes represent the digital value, and vertical axes of the lower and upper graphs represent the X-ray dose value and optical diffuse density, respectively. On the upper graph, results of both ink-jet and dry imager system are depicted. From this result, it's found that the ink-jet output has almost linear characteristics similar to the dry imager output, furthermore it has enough density range up to more than 3.0. To obtain the optical density more than 3.0, CXJ-3000 has a capacity to overstrike multiple ink dots.

Next, we measure the sensitivity characteristics. Sensitivity is one of the most important characteristics to evaluate the effectiveness of the output system not only for the medical imaging. In this study, we employ the Contrast Transfer Function(CTF) to measure the sensitivity by using the micro densitometer. To measure the sensitivity, we have to consider the anisotropic characteristics of the imaging system and the printing system. Here we measure the two directions, one is the parallel direction to the imaging/printing head movements, which is called 'main scanning direction' in this paper. Another is the roll direction of the imaging plate or the film, which is called 'sub scanning direction'.

Fig.4 represents the CTF value of main scanning direction(a) and sub scanning direction(b). To measure the CTF, the square-wave chart on the imaging plate is exposed by X-ray imaging system. This chart has 8 kinds of frequencies which are from 0.5 to 5 (lp/mm). The value denoted as 'Input' means the output of the CR system. From these results, the ink-jet printing system has a little advantage to the dry imager, especially the advantage from 3 to 4 (lp/mm) in the sub scanning direction is significant. Such good results seem to be caused by the high resolution property of the ink-jet printing system.

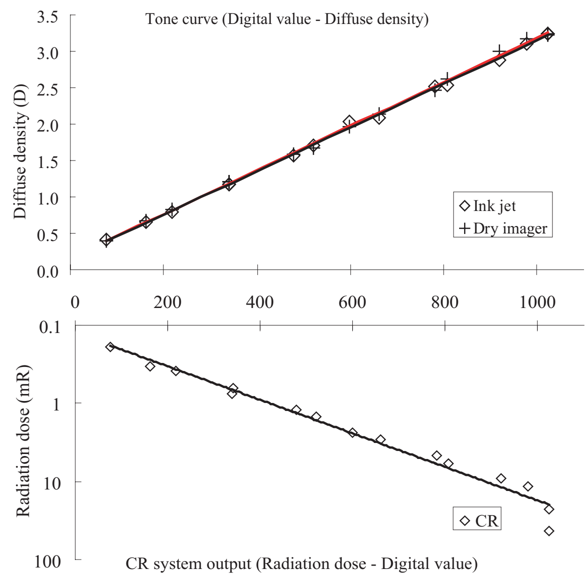


Figure 3: *The lower and upper graphs represent the tone reproduction characteristics of the CR system and printing systems, respectively.*

Next, wiener spectrum is measured for the physical evaluation of X-ray image noise as shown in Fig.5. This measurement is also performed for two directions. The main directions are represented in Fig.5(a),(c), and the others are in Fig.5(b),(d). Furthermore, the optical density is varied for $OD = 1.0$ and $OD = 2.0$. Though wiener spectrum is measured with only $OD = 1.0$ in general, we additionary compare the wiener spectrum with $OD = 2.0$ since the noise effect is caused by overstriking operations. From these results, it's found that wiener spectrum with $OD = 1.0$ is almost the same and the ink-jet output has a little advantage for less than 1 (lp/mm). On the contrary, wiener spectrum with $OD = 2.0$ represents the big disadvantage of the ink-jet output for more than 1 (lp/mm). Such disadvantage is caused by the overstring operations due to gain the maximum density.

From results of CTF and wiener spectrum, we figure out the overall evaluation of physical properties as follows,

$$E_p = \frac{CTF^2}{\text{Wiener spectrum}}.$$

If E_p is larger, the printing system has better physical properties. The results E_p for all cases are shown in Fig.6. We vary the directions and optical density also in this experiment. As we can see from these results that in the cases of $OD = 1.0$, the ink-jet printing system has a little advantage to the dry imager. On the contrary, in the cases

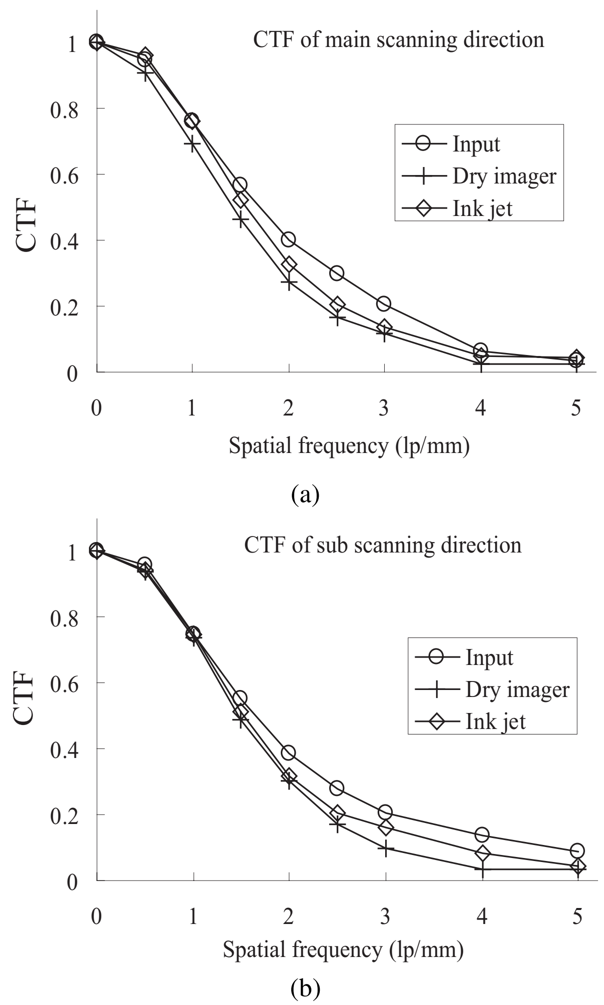


Figure 4: *CTF of (a)main scanning direction, (b)sub scanning direction*

of $OD = 2.0$, the dry imager printing system has a little advantage to the ink-jet printing.

Because the ink-jet printing performs the area coverage modulation, such physical properties strongly depends on its algorithm[6]. The present implemented algorithm is based on the LUT transformation to obtain the linear tone reproduction characteristics as shown in Fig.3. Then the improvement of the printing algorithm is the future subject of the medical ink-jet printing system.

Subjective evaluation

To evaluate the effectiveness of the medical printing system, only physical properties is not enough but the subjective evaluation by the medical doctors is very important. So we examine two subjective evaluations, the first one is the human visual evaluation of sensitivity by using the burger phantom and the second one is the clinical evaluation by using the ROC analysis.

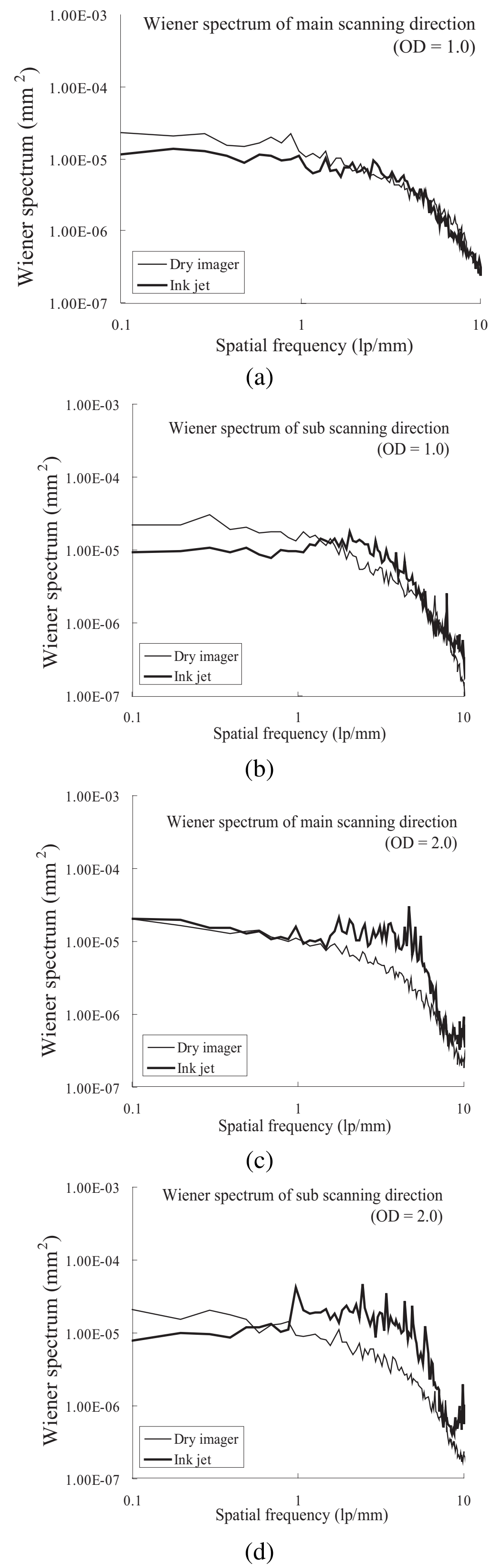
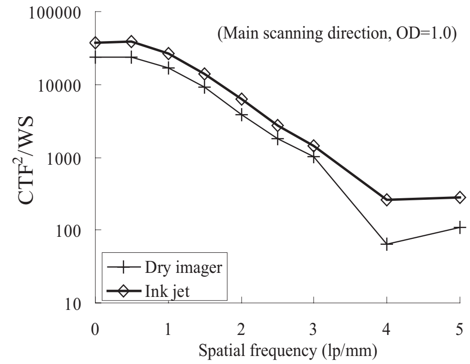
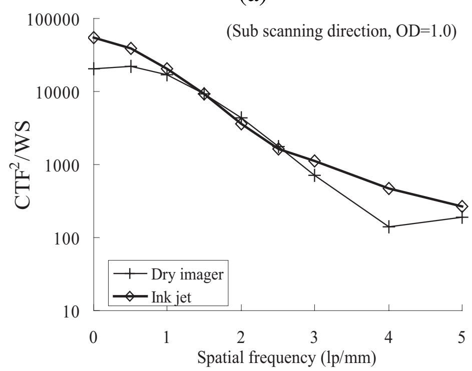


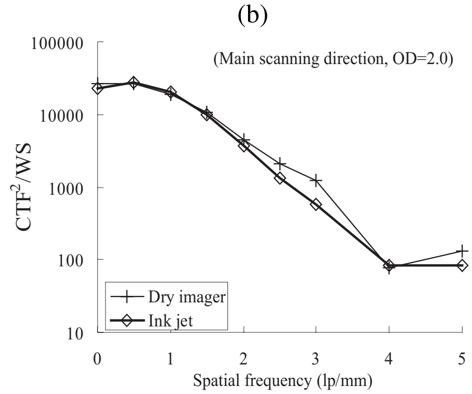
Figure 5: *Wiener spectrum of main (a),(c) / sub (b),(d) scanning direction at OD=* 1.0*(a),(b) / OD=* 2.0*(c),(d).*



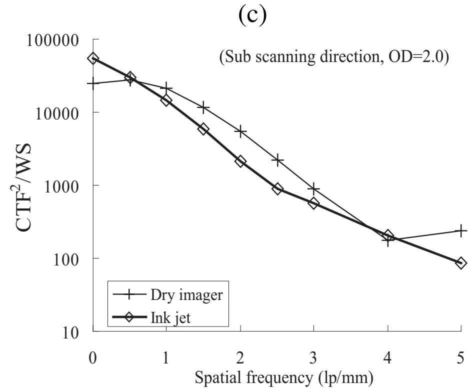
(a)



(b)

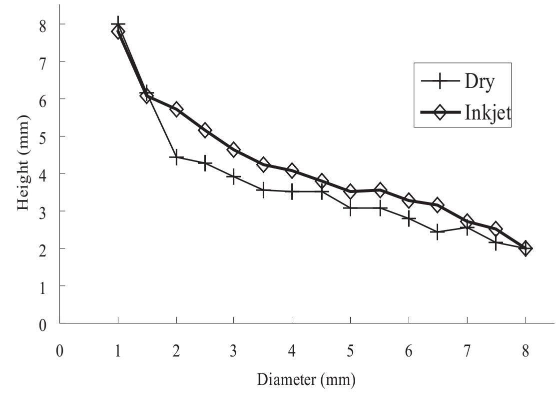


(c)

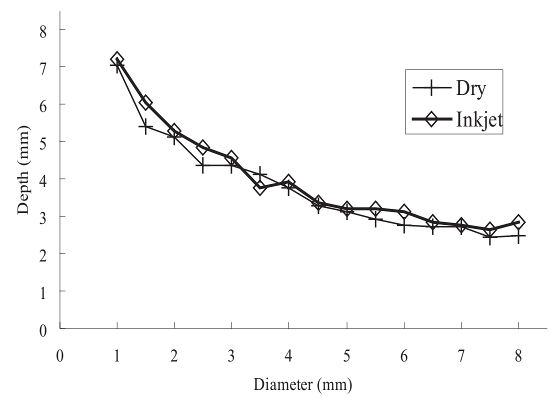


(d)

Figure 6: *CTF^2/(Wiener spectrum) of main (a),(c) / sub (b),(d) scanning direction at $OD = 1.0$(a),(b) / $OD = 2.0$(c),(d).*



(a)



(b)

Figure 7: *The result of burger phantom evaluation. (a) Convex type burger phantom, (b)concave type burger phantom*

During the sensitivity evaluation, the convex and concave burger phantoms are taken by X-ray imaging system with the 12cm thickness acrylic resin as the scattering object. The burger phantom is the test chart for visually evaluation of the sensitivity and it has various diameter/height convex(or concave) acrylic resin small objects. After that, these imaging data are printed out by the dry imager and the ink-jet system, and printed films are evaluated by 4 radiological technologist and 4 radiological students. The results of these evaluations are shown in Fig.7, where Fig.7(a) and (b) are the results of the convex and concave type burger phantoms, respectively. The horizontal axis of these graphs means the diameter of the acrylic column on the burger phantom, and the vertical axis of them means the height of the acrylic column. In these graphs, the minimum height of the acrylic column that can be perceived by the reader for each diameter is

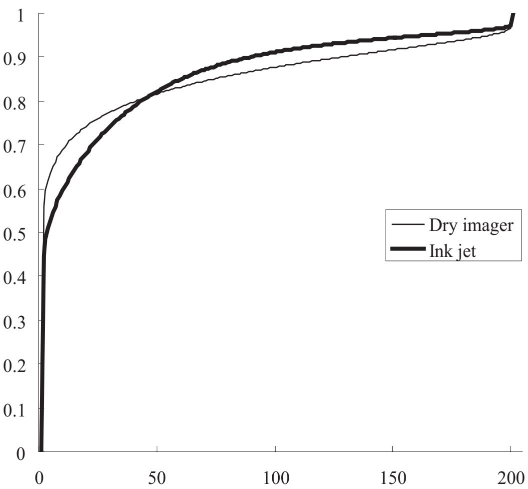


Figure 8: *The result of ROC analysis*

plotted. So the less value means the higher sensitivity of the printing systems. From these results, it's found that almost the same results are obtained in the case of concave burger phantom as shown in Fig.7(b), but the dry imager has some advantage in the case of convex burger phantom as shown in the Fig.7(a). Since these results are related to the diagnostic capacity, it is very important to modify the printing algorithm for improving this evaluation.

Next, we examine the ROC(receiver operating characteristic) analysis by using clinical images, where we use 20 examples of abnormal finding in the chest X-ray film and 20 examples of normal finding in the chest X-ray film. These images are distributed as standard digital images by the Japan Radiological Society. In addition to these examples, we use more 10 examples of chest X-ray film with nodular shadow, which are taken in our university hospital. These printed images are evaluated by three internal medicine of respiratory and three radiologist, and reading results are performed the ROC analysis with continuously-distributed test. The results of the ROC analysis are shown in Fig.8, where the mean Az value of the dry imager is 0.858, and the mean Az value of the ink-jet system is 0.865. From this result, the ink-jet printing system has quite similar characteristics to the dry imager, we can't judge which system has an advantage. In general, ROC analysis is the most reliable index to evaluate the diagnostic capacity. So it can be said that ink-jet printer has enough quality for medical imaging.

Conclusion

In this study, we compared the conventional dry imager printing system and the ink-jet printing system at the points of physical and subjective evaluations. In the physical evaluations, tone reproduction of each system has almost linear characteristics. After the CTF measurement, the ink-jet printing system has a little advantage because of its high resolution. As the noise evaluation, we measure the wiener spectrum. From this results, the ink-jet system has an advantage for optical density $OD = 1.0$, however it has a disadvantage for $OD = 2.0$. The ink-jet system uses the overstriking of ink dots to gain the optical density, it causes such a noisy characteristics. In the subjective evaluations, we perform the visual sensitivity evaluation by using the burger phantoms. Though the ink-jet system has a little disadvantage when using convex type burger phantom, it can be said that they have almost the same properties. Results of ROC analysis represent that the ink-jet system has enough quality in comparison to the conventional dry imager.

Since the printing quality of the ink-jet system depends on its algorithm so the future subject of this study is the improvement of the algorithm specialized for medical imaging.

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Biography

Jun Yamashita was born in 1979, received B.E. degrees in Information and Image Sciences, M.E. degrees in Science and Technology, from Chiba University, Chiba, Japan in 2002 and 2004, respectively. He became Ph.D course student from April, 1, 2004. His research interests are in Color sciences, Medical imaging and Ink-jet printing.