Continuous Ink Jet Printing of Digital Radiographs and Other Medical Images

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As a consequence of the development of digitally based imaging systems for medical diagnosis, means for image display will change. The interpretation of images will gradually transgress from the traditional viewing of films on a light box towards the use of viewing stations based on high resolution CRT monitors. However, the need for hard copies will probably remain even with future fully implemented digital image management systems.

The Hertz' continuous ink jet technology[1], developed at the Department of Electrical Measurements, Lund Institute of Technology, offers an interesting alternative to today's hard copy production methods mainly based on photographic film. The combination of true halftones by variable dot size and a spatial resolution of 10 pixels/mm offers prints of very high quality in black-and-white as well as in color [2]. With comparably low cost paper as a print medium it is possible to produce hard copies at a material cost far below that of film.

Two studies for evaluating the quality of ink jet-printed paper copies of digital medical images have been performed. In both studies, a printer for gray scale images was employed. It was equipped with a single-nozzle print head supplied with black ink.

Originally published in *Proc. of IS&T's 46th Annual Conference*, May 9-14, 1993 in Cambridge, Massachusetts.

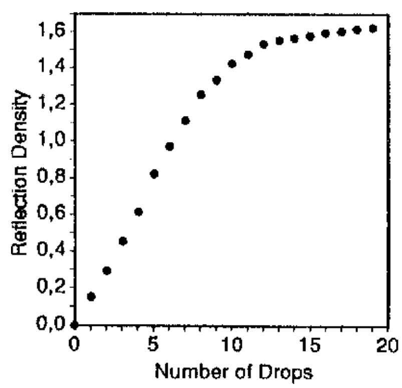
Print Quality for Demonstration

Materials and Methods

The first study[3] included images from a number of different imaging modalities: computed tomography, magnetic resonance imaging, digital subtraction angiography and ultrasound imaging. Emphasis was, however, laid on digital projection chest radiographs, which were derived from a computed radiography (CR) system based on photo-stimulable luminescence plates [4]. Chest images were selected because they are among the most critical types of radiographic images, having a wide range of contrast and spatial resolution.

Since the data for all images was available only in a raw non-processed format, effort was laid on the processing of image data in order to get ink jet-printed images with as much information as possible. Window adjustment, gamma correction and edge enhancement by unsharp-mask algorithms were performed.

The goal of this study was to ascertain if the quality of the ink jet-printed images could be made high enough for demonstration purposes and to find an optimum combination of both paper and means for viewing. Two different kinds of paper substrates were tested: a baryta coated paper suitable for viewing with transmitted light, and a special ink jet matt coated paper, to be viewed with reflected light. During a number of sessions, a consensus group of experienced radiologists and imaging scientists examined each separate ink jet-printed image. Prints on



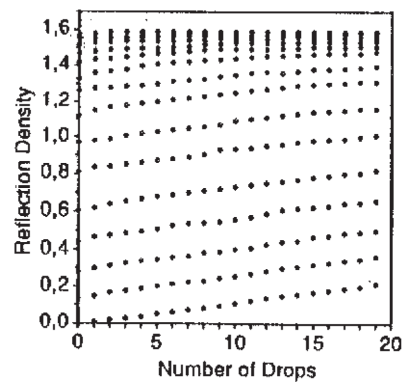


Figure 1. Reflection density (RD) as a function of number of drops in each pixel. (a) Measured density levels created by the ink jet printer supplied with ink of only one density. (b) Measured density levels as created by the ink jet printer combining ink drops of two differently densed inks, printed "on top" of each other.

the different paper substrates, viewed by the different means, were compared to corresponding images recorded on film.

Results

The consensus from this first study was that the ink jet-printed images were well suited for demonstration [3]. The optimum combination of paper substrate and means for viewing showed to be the matt coated paper viewed as an on-sight image, i.e., with reflected light. All information of interest in the film images, e.g., tumors, catheters and pneomothorax conditions, was also clearly visible in the ink jet-printed paper images.

Print Quality for Diagnosis

Materials and Methods

A second study was performed to evaluate if the quality was high enough also for diagnostic tasks. This study was carried out as a receiver operating characteristic (ROC)[5] study with digital chest radiographs derived from a CR system. Eighty-three images of a chest phantom, having simulated tumors in the mediastinum and the right lung, were reviewed by six radiologists. The images were presented in two series: as ink jet-printed paper copies and as film hard copies produced in the CR system laser recorder. The images, with matrices of 1760 x 2140 pixels, were printed with the same spatial resolution on film as on paper, i.e., 10 pixels/mm. On film, every image was recorded in two versions, one optimized in density range for the mediastinum and one for the lungs, whereas on paper, only one image was printed constituting an effort to optimize both the mediastinum and the lungs.

Results

From calculations on the average performance of the six observers, no significant difference was found (critical significance level = 0.05) between the performance of film and that of ink jet-printed paper copies. This is noteworthy, since each image on film was presented in two different versions, optimized for the mediastinum and the lungs, respectively, whereas only one ink jet-printed image was made for concurrent evaluation of both the mediastinum and the lungs in a single image.

Discussion

At the future radiology department, when the diagnostic work will be performed on monitors, hard copies will be necessary only for demonstration purposes. Our results so far show that the ink jet printer is capable of producing paper copies of digital medical images with a quality high enough for at least this application. Since the cost per copy of an ink jet print is only around one tenth of that of a film hard copy, a considerable economic gain could be achieved by using ink jet-printed paper copies. The use of paper images further gives the viewer the advantage of being able to study the image anywhere, independent of access to a light box.

The time to print a full size image of 360×250 mm^2 is 4.5 minutes. This time is longer than the time needed to record and develop a corresponding film image. However, by using a multi nozzle print head, as the one used in the four-color printer [2, 6] but only black ink in all four nozzles, the print time can be reduced to below the time for a film recording-and-developing procedure.

Since the ink jet prints probably will be used for demonstration primarily, the quality demand will not necessarily have to be equal to that of film. However, the ink jet print quality can be further improved. Today the maximum number of available true density levels is limited to 32 (figure 1a). A combination of these discrete density levels over a small area of adjacent pixels, using an error-diffusion algorithm[7], yields a possibility to produce density levels represented by pixel values from 0-255.

In the lowest density region, the combination algorithm results in noise and inferior small detail reproduction. This problem can, however, be solved by the use of two differently densed inks. Preliminary results have shown that it is possible to create intermediate levels that extend the current number of true density levels, i.e., without any use of error-diffusion, to around 150 (figure 1b). Further studies will show how much this improvement will affect the quality of the radiographic images.

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