MOIRE PATTERNS FROM PLAIN RADIOGRAPHS OF TRABECULAR BONE

Robert S. Siffert[1], Gangming Luo[1] and Jonathan J. Kaufman[1,2]

[1]Mount Sinai School of Medicine, MS 1188, One Gustave L. Levy Place, New York, NY 10029
[2]CyberLogic, Inc., 611 Broadway, Suite 707, New York, NY 10012

ABSTRACT

Trabecular bone strength and integrity are related to both bone mass and architecture. Current methods for assessing architecture in vivo are limited. This study investigates the synthesis of moire patterns as a potential means for assessing trabecular bone. Plain radiographs of the human calcaneus are digitized, thresholded, rotated and nonlinearly superimposed to derive a moire pattern associated with the original radiographic image. The moire patterns may provide an enhanced means for classifying and analyzing trabecular bone structures compared to or in conjunction with individual (non-superimposed) radiographic images. Another feature of this paper is the description of a local thresholding method for segmenting the radiograph into a binary (bone/no-bone) image. This is potentially useful for stereological analysis of radiographs.

INTRODUCTION

Trabecular bone strength is a function of both bone mass and architecture. Mass accounts for about 65 percent of the observed variation in bone strength, and architecture can explain about 20-25 percent more of the variation. Although clinical bone mass measurements are routinely made, no simple method currently exists for determining trabecular architecture *in vivo*. Such a method in conjunction with bone mass measurements could have wide use for assessing bone fracture risk in osteoporosis.

Previous studies have attempted to evaluate architectural changes in trabecular bone using texture and fractal analyses of plain radiographs [1,2]. Although these methods do appear to provide some information on the architectural states of trabecular bone, there is also a large artifactual component related to the inherent variability of the overall radiographic process, including for example, exposure, film development and overlying soft tissue.

This study presents some preliminary results on synthesizing moire patterns associated with plain radiographs of the human heel. The long range objective is to determine if moire patterns can provide an enhancement in the ability to assess trabecular architectural features while maintaining better immunity to exposure and other artifacts, compared to using the original radiographic image itself.

METHODS

Moire Pattern

The moire effect denotes "a fringe pattern formed by the superposition of two grid structures of similar period" [3]. In the synthesis approach taken here, the moire pattern is produced by superimposing a rotated copy with the original (and not rotated) image. The process is carried out as follows. The relationship between the pixel value B_1 of the digitized image and bone density ρ is assumed to be:

$$B_1 = 255(1 - e^{-a \times \rho}) \tag{1}$$

where *a* is a constant. At a given location, the original image is assumed to have pixel value B_1 and the rotated image pixel value B_2. Using Eq. (1), it can be shown that superposition of the two images at the given location results in pixel value B, where B is given by

$$B = B_1 + B_2 - \frac{B_1 \times B_2}{255} \tag{2}$$

Thus, for two given digital images, image 1 and image 2, a moire patten can be synthesized in the following way:

(1) Pick a point in image 2 as the center (x_c, y_c) and select an angle θ to rotate the image around the center. The formula for rotation is:

$$\begin{gathered} x_r = x_c + r \times \cos(\vartheta) \\ y_r = y_c + r \times \sin(\vartheta) \\ and \\ r = \sqrt{(x - x_c)^2 + (y - y_c)^2} \end{gathered} \tag{3}$$

where (x_r, y_r) is the coordinate after the rotation and (x, y) is the coordinate before the rotation;

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(2) Superimpose image 1 and rotated image 2 by using Eq. 2 to obtain the pixel value for the superimposed image. (Note that this algorithm allows each image to be distinct, although in what follows the moire pattern is obtained by rotating the original image with respect to itself.

Local threshold

A local threshold is used to create a binary image from the gray level digitized radiograph. For a given digital image, let B(x,y) be the 8-bit pixel value for any given point (x,y). A threshold image T(x,y) is then created by using the following formula:

$$T(x,y) = \frac{\int_{y-\Delta}^{y+\Delta} \int_{x-\Delta}^{x+\Delta} B(\xi,\eta)\, d\xi\, d\eta}{\Delta^2} \qquad (4)$$

where Δ is the dimension of a small area over which T(x,y) is defined. After the creation of the threshold image, the local threshold is defined as

$$B'(x,y) = \begin{cases} 255 & \text{if } B(x,y) > T(x,y), \\ 0 & \text{if } B(x,y) < T(x,y). \end{cases} \qquad (5)$$

where B'(x,y) is the new binary image after local thresholding.

RESULTS

A digitized radiographic image of a human calcaneus is shown in Fig. 1. A moire pattern is shown in Fig. 2 and was created using the image in Fig. 1 (as both image 1 and image 2) by rotating the image 5° around its center. Applying the local threshold method with $\Delta = 17$ pixels to the image in Fig. 2 results in the (binary) moire image of Fig. 3.

DISCUSSION AND CONCLUSION

Moire patterns have a long history of applications in many fields. This study demonstrates that radiographic images of trabecular bone can be manipulated to produce moire patterns also. Whether these patterns can provide useful information with respect to bone architecture and strength remains to be seen. However, the methods presented here can serve as a basis for further research. In addition, the local thresholding technique described here may be useful for carrying out radiographic based sterological studies on trabecular bone.

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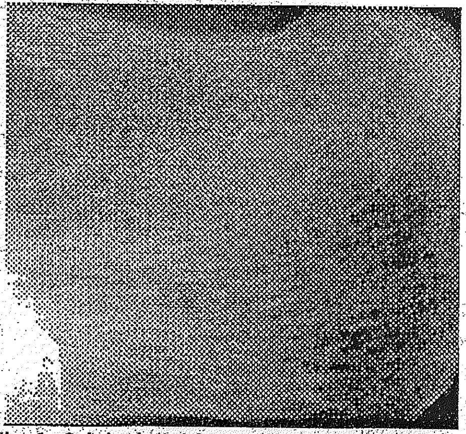

Fig. 1. Original digitized radiographic image of os calcis.

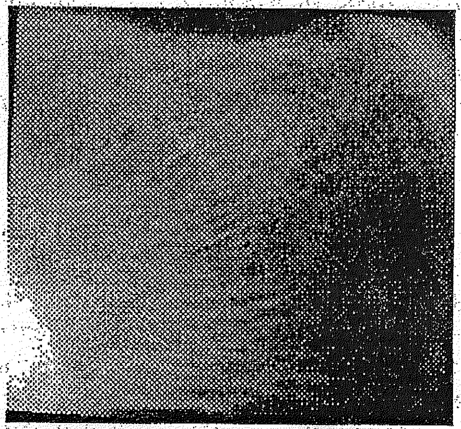

Fig. 2. Moire pattern associated with Fig. 1.

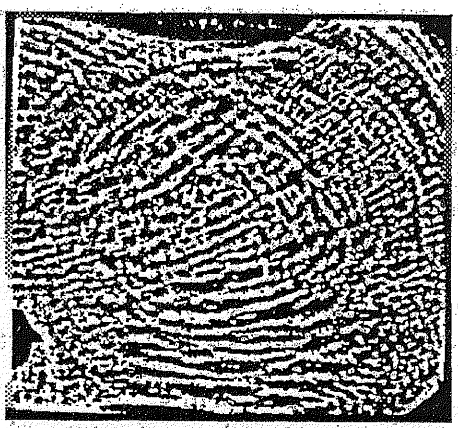

Fig. 3. Thresholded image associated with Fig. 2.