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Digital Processing of Breast Thermograms

by

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The Artificial Intelligence Center of SRI has pioneered the development of pattern-classification and scene-analysis techniques* for more than a decade. In an effort to apply such disciplines to medical problems, the Institute has digitized and processed a series of breast thermograms of positive patients.**To improve the medical value of such imagery for the radiologist, several off-the-shelf algorithms have been applied to the digitized images. Figure 1 contains a halftone reproduction of a digitized thermogram. (The inverted horizontal line is an intentional artifact of the IR scanner.) Figure 2 is a centered and enlarged (zoomed) version of the Figure 1 image. Note the appearance of additional detail resulting from the zooming operation.

Figures 3 and 4 represent attempts to enhance the visibility of the thermographic imagery. In particular, Figure 3 was generated by enhancing the contrast of Figure 2. The imagery was enhanced by passing the picture through a fictitious photographic process with a high-contrast (high-gamma) film. The process results in darker blacks, lighter whites, and more distinguished grays; contrast enhancement thus makes better use of the dynamic range of the human eye. Similarly, Figure 4 was produced by crispening Figure 3. The imagery was crispened by first decomposing the picture into its Fourier components, then boosting the high spatial frequencies, and finally recomposing the picture to form the crispened image. The crispening process thus tends to reduce the strength of the large uniform areas and increase the strength of the small detailed ones. Edge crispening thus improves the visibility of fine image structure.

* R. Duda and P. Hart; Pattern Classification and Scene Analysis (Wiley - Interscience, New York, 1973)
**The breast thermograms were taken by Solon Finkelstein, M.D., of Palo Alto Medical Clinic with a Spectrotherm camera.
Figures 5 through 8 demonstrate the use of pseudo-color techniques with breast thermograms. Pseudo-color displays provide a powerful technique for overcoming the limited contrast sensitivity of the human eye. As a rule, the human eye can distinguish about fifty brightness levels relative to the ambient. In other words, a breast lesion must be about 2% brighter than its immediate surroundings to be seen by the human eye. On the other hand, the human eye can distinguish thousands of color hues at a given brightness level. To take advantage of this better color sensitivity, one can convert the brightness levels of a monochrome picture to corresponding hues for a color display. In particular, low-brightness regions (Figure 5) can be converted to blue, medium-brightness ones, (Figure 6) to green, and high-brightness ones, (Figure 7) to red. When displayed simultaneously, one obtains a pseudo-color image (Figure 8). Since small brightness differences become large color differences, the detectability of lesions is markedly improved.

Besides improving the visibility of the breast thermograms, the digital computer can also analyze the breast thermogram for unusual thermal features. Figure 9, for example, contains crosses marking the hottest and coldest points of the thermogram. Further processing might enlarge on this algorithm and locate the hottest areas of the picture, with the size, topology, and location of the area controlled. For example, the computer might look for hot spots and signal their presence to the attending physician. The same procedure could also detect periareolar heating or engorged venous systems. From an image-processing viewpoint, such tasks represent quite reasonable undertakings.

Profiles and histograms represent another approach to the analysis of breast thermograms. Figure 10, for example, contains a vertical profile of the Figure 2 image. (The vertical profile was obtained by simply averaging the picture elements in each horizontal row of the
The sharp spike corresponds to the inverted line discussed earlier, and the broad hump on the right represents the inframammary fold. Generally speaking, the profile looks normal. Figure 11 contains a horizontal profile of Figure 2. The broad hump in the center corresponds to the cleft between the two breasts. The right side of the curve is obviously hotter than the left, an anomalous condition. Such imbalance suggests that further examination—e.g., mammography and palpation—of the patient is warranted.

Temperature histograms also signal differences between the right and left breasts. Figure 12, for example, contains a histogram of the temperatures found in Figure 2. The main hump represents the basic distribution of breast temperatures; the smaller hump on the right probably represents the inframammary fold and interbreast cleft. Figures 13 and 14 contain, respectively, the temperature histograms for the left and right sides of Figure 2. Note that the right side features higher temperatures than the left, another suspicious indicator of breast cancer. Detailed inspection of Figure 2 suggests a problem in the superior region of the right breast. In particular, the heat band running from the interbreast cleft to above the right nipple is definitely anomalous, and indicates the patient should receive follow-up examination.
FIGURE 1  DIGITIZED BREAST THERMOGRAM
FIGURE 2  ZOOMED AND CENTERED THERMOGRAM
FIGURE 3  THERMOGRAM WITH CONTRAST ENHANCEMENT
FIGURE 4 THERMOGRAM WITH CONTRAST ENHANCEMENT AND EDGE CRISPENING
FIGURE 5  COLD PORTION OF THERMOGRAM (BLUE)
FIGURE 6  WARM PORTION OF THERMOGRAM (GREEN)
FIGURE 7  HOT PORTION OF THERMOGRAM (RED)
FIGURE 8 PSEUDO-COLOR BREAST THERMOGRAM (MONOCHROME)
FIGURE 9  HOTTEST (WHITE CROSS) AND COLDEST (BLACK CROSS) POINTS OF THERMOGRAM
FIGURE 10  VERTICAL TEMPERATURE PROJECTION
FIGURE 12  FULL BREAST TEMPERATURE HISTOGRAM
FIGURE 14  RIGHT BREAST TEMPERATURE HISTOGRAM