A Fuzzy Approach to Digital Mammographic Feature Enhancement

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Abstract

Mammography plays a major role in the earlier detection of breast cancer in asymptomatic women. Computer-aided mammographic screening can significantly increase the efficiency of diagnoses. This paper presents a fuzzy approach to enhance the contrast of digital mammograms. The levels of contrast enhancement are adapted to obtain better performance. Furthermore, the cross-over point is automatically determined based on the features of mammographic images. The proposed approach can remove the irrelevant details, enhance the contrast as well as preserve the image features effectively according to the quantitative criterion and human expert judgement.

1 Introduction

Breast cancer continues to be a significant public health problem in the United States. It was estimated that 182,000 new cases of breast cancer would have been diagnosed and 46,000 women would have died of breast cancer. One out of eight women will develop cancer at some point during her lifetime in this country [11]. Primary prevention seems impossible since the causes of this disease still remain unknown. Early detection is the key to improving breast cancer prognosis. Computer-aided mammographic screening provides a promising solution to this task. However, digital mammograms are of usually low contrast, and have nonuniform backgrounds. Abnormalities may have ill-defined and obscured margins. Inhomogeneity and variability of normal tissue and fat also cause difficulties in computer-aided diagnoses. To enhance the suspicious areas is the first and important step of automated diagnoses. [8] employed a selective median filter with a 5 × 5 window for circumscribed mass enhancement. This method can remove noise effectively, but cannot enhance the contrast of the suspicious areas. Unsharp masked filters are frequently used in medical images for contrast enhancement [10], but it could also enhance the noise easily [2].

Fuzzy set theory becomes a popular tool for image processing [9]. [4] introduced an image contrast enhancement technique using the concept of fuzzy sets. Nevertheless, the cross-over point and the levels of enhancement are selected subjectively. Recently, [6] proposed a method to select a cross-over point by minimizing the classification error. However, it would not be correct when the normal distribution assumption does not hold. In this paper, we present a fuzzy approach to digital mammographic feature enhancement. The cross-over point is selected by maximizing an edge sensitivity measure and the levels of enhancement are determined by the degrees of a membership function. Additionally, a multiplication operator is utilized to enlarge the range of intensities. The performance evaluation is evaluated according to the quantitative criterion and human expert judgement.

The organization of this paper is the following. The usage of fuzzy enhancement is given in Section 2. The selection of the cross-over point is discussed in Section 3. Finally, the preliminary results and the conclusions are described in Section 4 and Section 5, respectively.

2 Fuzzy Sets and Fuzzy Enhancement

Fuzzy set theory has been proven to be useful in many areas of image processing. Since mammographic images have some kinds of ambiguities such as indistinct borders, ill-define shapes, and different densities, it is proper to apply fuzzy logic rather than ordinary methods. The main application of fuzzy set theory s to transform ordinary domain data to fuzzy domain represented by the degrees of a membership function, and to perform all operations in a fuzzy domain.

Let X be an image with size M × N and L grey levels. Let x_{mn} be the grey level at location (m,n) in X, where m = 0, 1, ..., M - 1, n = 0, 1, ..., N - 1, and $\mu_X(x_{mn})$ be the value of the membership function in the unit interval [0, 1] which represents the degree of some brightness property $\mu_X(x_{mn})$ by the pixel intensity x_{mn}. By mapping an image X from x_{mn} into $\mu_X(x_{mn})$, the image set X can be written as

$$\mathrm{X} = \{(x_{mn}, \mu_X(x_{mn}))\} \qquad (1)$$

Then, μ_X can be viewed as a characteristic function as a weighting coefficient which reflects the ambiguity in X.

A function mapping all the elements of a crisp set into real numbers in [0, 1] is called a membership function. The larger values of the membership function represents the higher degrees of the membership. It means how closely an element resembles an ideal element. Membership functions can identify the uncertainty using some special functions. These functions transform the linguistic variables into numerical calculations by setting some parameters of memmbership functions. The fuzzy decisions can then be made.

Three steps are established for fuzzy enhancement [4]. First, fuzzification maps the ordinary domain data to fuzzy property domain data by a membership function [9]. Then, Intensification transforms a fuzzy set A to another fuzzy A' such that the values, which are above 0.5, of a membership function would be increased and would be decreased for those below 0.5. Finally, an inverse transformation is performed to map the fuzzy data to ordinary domain. The key concept of the proposed fuzzy enhancement is to use a contrast intensification operator INT and the levels of enhancement are adapted according operator INT and the levels of enhancement are adapted according to the values to the values of membership function. The implementation of the proposed algorithm is given in the following.

STEP 1: *Fuzzification* - The image data are mapped into the fuzzy property domain using a membership function shown as follows [4].

$$\mu_X(g) = \begin{cases} 0 & if\ g \leq a \\ \frac{1}{2}\left(1 - \frac{b-g}{b-a}\right) & if\ a \leq g < b \\ \frac{1}{2}\left(1 + \frac{g-b}{c-b}\right) & if\ b \leq g < c \end{cases} \qquad (2)$$

where g is a grey level of the original image, b is the cross-over point, and a and c are the minimum and maximum intensities of an image.

STEP 2: *New Contrast Intensification* - The levels of contrast intensification are adapted according to the values of the membership function shown as the following.

$$\mu'_X(g) = \begin{cases} \frac{1}{2}\left(1 - \left\{\frac{sin[\Theta_1(1-2\mu_X(g))]}{sin\Theta_1}\right\}^{\mu_X(g)}\right) \\ \qquad if\ 0 \leq \mu_X(g) \leq 0.5 \\ \frac{1}{2}\left(1 + \left\{\frac{sin[\Theta_2(2\mu_X(g)-1)]}{sin\Theta_2}\right\}^{1-\mu_X(g)}\right) \\ \qquad if\ 0.5 \leq \mu_X(g) \leq 1 \end{cases} \qquad (3)$$

where $\mu'_X(g)$ is a new membership value, Θ_1 is an angular equivalence of black band and Θ_2 is an angular equivalence of white band. Θ_1 and Θ_2 are fixed to a constant as $\pi/2$.

The idea of this contrast intensification is to keep the membership value $\mu_X(0.5)$ unchanged, and to enhance the contrast according to the membership value. It provides better contrast enhancement in different kinds of mammographic images.

STEP 3: *Defuzzification* - The defuzzification operation is an inverse transformation of Eq. (2) given as following [4].

$$g' = \begin{cases} b - (b-a)(1 - 2\mu'_X(g)) \\ if \quad 0 \leq \mu'_X(g) \leq 0.5 \\ b + (c-b)(2\mu'_X(g) - 1) \\ if \quad 0.5 \leq \mu'_X(g) \leq 1 \end{cases} \qquad (4)$$

where g' is a new grey level.

In addition, a multiplication operator is used to enlarge the range of intensities shown as follows.

$$f(x,y) = \frac{g(x,y)^n}{L_{max}} \qquad (5)$$

where $f(x,y)$ is a new grey level at the location x and y, $g(x,y)$ is a enhanced grey level using Eq. (4), L_{max} is the maximum intensity, and n is a constant. We employ $n = 2$ in this paper.

The performance of the fuzzy enhancement algorithm depends on the selection of the cross-over point. The intensities above the cross-over point would be increased. On the other hand, the intensities below the cross-over point are decreased. The selection of the cross-over point is discussed in the next section.

3 Cross-over Point Selection

The performance of fuzzy enhancement is based on the selection of the cross-over point. Cross-over point can be chosen depending on different kinds of applications [3]. In this study, we would like to increase the intensities of the suspicious areas which membership values are above 0.5, to decrease the intensities of the background which membership values are below 0.5, to remain the intensities of the boundaries of the suspicious areas which membership values are equal to 0.5. Therefore, the cross-over point is determined by maximizing the edge sensitivity measure.

A contrast histogram indicates that the low region belongs to the fat tissue and the high region belongs to features [5]. The basic postulate of the proposed approach is that a suspicious mass is brighter than the average breast tissue.

Usually, the suspicious masses are much smaller than the breast tissue. Global measurement may not be reliable for detecting a small object like a suspicious mass. Local measurement may then be useful. In this paper, region of the breast is located and a median filter is then applied [7]. The highest peak of the region of the breast histogram is selected as the average intensity of breast tissue denoted as P. Since, we assume the suspicious masses are brighter than average breast tissue, the cross-over point can be selected between P and the maximum intensity of the region of the breast histogram. An edge sensitivity measure is introduced for selecting the cross-over point. The edge sensitivity measure, denoted as ε, is given as follows.

$$\varepsilon(f(x,y)) = \sum_{x,y \epsilon R} \sum \varphi(f(x,y)) \quad (6)$$

$$b = Arg \max_{P<i<L_{max}} \varepsilon(i) \quad (7)$$

where R is the region of the breast, b is the cross-over point, φ a edge detector mask, and $f(x,y)$ the grey level at the location x and y.

In this paper, we employed the Sobel edge detector mask [7] as φ. Eq. (6) computes the edge sensitivity for every grey level. Then, the cross-over point may be selected by maximizing the edge sensitivity measure using Eq. (7).

4 Preliminary Results

All test mammograms have been proven by biopsies. The enhanced masses do not need to be malignant diseases but suspicious areas. Some experimental results are reported in Figure 1 to Figure 8.

An original mammographic image is shown in Figure 1. Its enhanced result is given in Figure 2. The enhanced mammographic image demonstrates that the contrast of the mass is enhanced. Moreover, the features such as the stellate shape and spiculated margin are well preserved.

Another set of original and enhanced mammographic images are shown in Figure 3 and Figure 4, respectively. The contrast of an irregular shape mass is enhanced. The enhanced mammographic image illustrates that the features such as ill-defined border and homogeneous density are well preserved. The irrelevant tissue is also removed.

A mammogram with a circumscribed mass is given in Figure 5. The enhanced image explains that the circumscribed mass is isolated shown in Figure 6. Another mammogram with a well circumscribed mass is given in Figure 7. The enhanced image, shown in Figure 8, has much higher contrast than the original image and the shape of the circumscribed mass is well preserved.

[1] investigated the performance of contrast enhancement for mammographic features by using computer-generated star-nodulars to test the contrast enhancement. We employed the same criterion for evaluating performance of the proposed approach with real clinical mammograms. Let I_1 be the average value of the pixels surrounding the suspicious areas, and I_2 be the average value of the suspicious region. The contrast C can be defined as

$$C = \frac{|I_1 - I_2|}{I_1 + I_2} \quad (8)$$

Then, the performance evaluation can then be measured by a relative contrast C_r

$$C_r = \frac{\text{contrast of the processed image}}{\text{contrast of the unprocessed image}} \quad (9)$$

To illustrate the performance of the proposed algorithm, some test mammographic images, including different kinds of shapes and densities shown in Figure 1 to Figure 8, are employed for the evaluation summarized in Table 1.

Table 1: The Proposed Approach Performance Evaluation

Mammograms	Relative Contrast
Figure 1 and 2	4.41
Figure 3 and 4	4.91
Figure 5 and 6	2.81
Figure 7 and 8	5.23
Average	4.34

Table 1 demonstrates that the proposed contrast enhancement performance is over most of the well known contrast enhancement algorithms [1]. Moreover, the proposed method is examined by using the real clinical mammograms rather than artificial mammograms [1]. The suspicious masses are well preserved without *a prior* knowledge of shapes shown in Figure 2, Figure 4, Figure 6, and Figure 8. Finally, the experimental results conclude that the proposed method not only enhances the contrast but also preserves the mammographic image features according to the quantitative criterion by a relative contrast [1], and visual judgement by human experts.

5 Conclusions

A fuzzy approach to digital mammographic feature enhancement is presented. The cross-over point is automatically selected based on the features of mammographic images. The levels of contrast enhancement are adapted according to the membership values. It provides better contrast enhancement in different kinds of mammographic images. The multiplication operator is then applied to enlarge the range of intensities. The basic postulate of the proposed method is that the intensities of suspicious areas are higher than the average intensity of breast tissue. High contrast enhancement and features preservation are the basic advantages of the proposed method. The proposed approach can remove the irrelevant details, enhance the contrast as well as preserve the image features effectively in accordance with the quantitative criterion and human expert judgement. It facilitates the further processes such as image segmentation, feature extraction, and classification.

References

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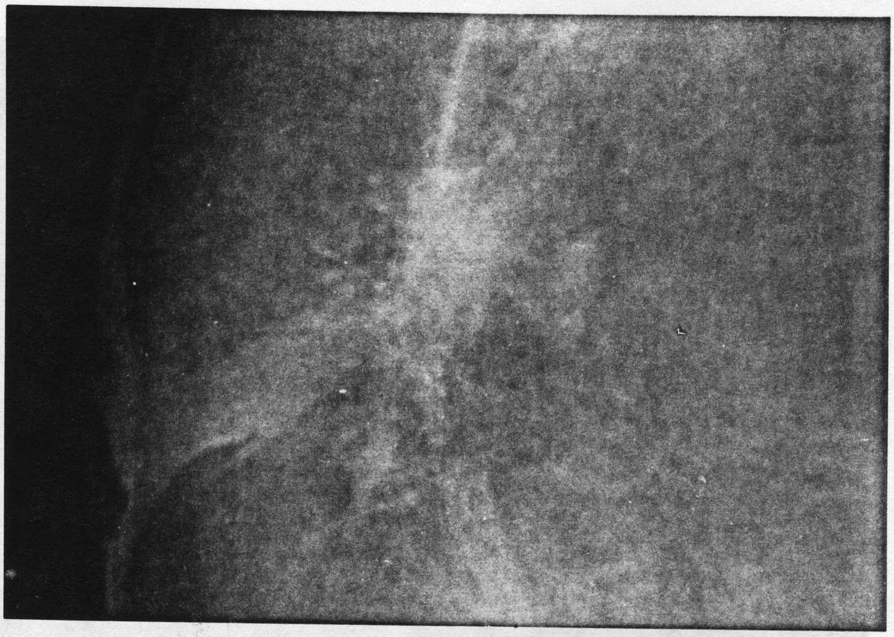

Figure 1: The Original Mammogram

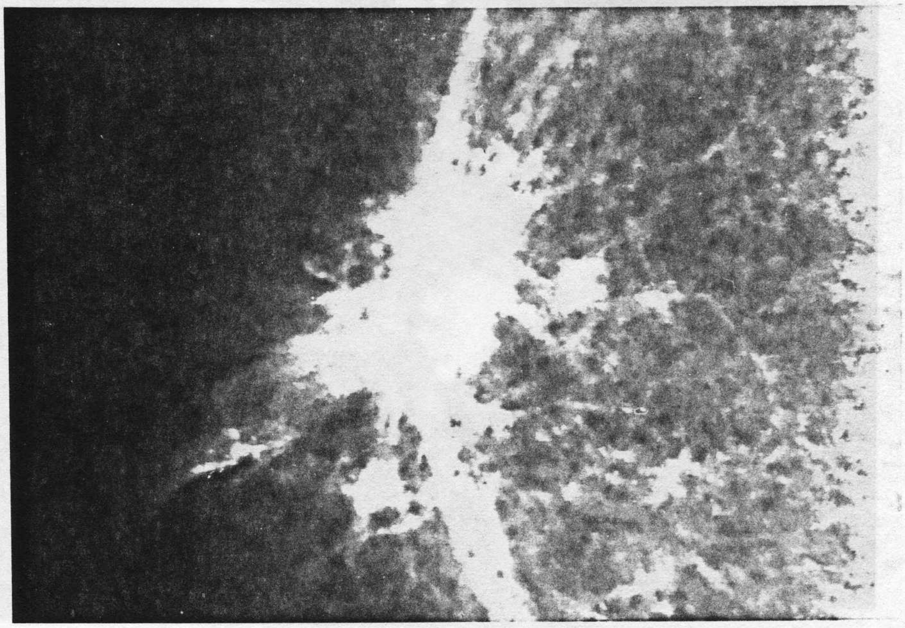

Figure 2: The Enhanced Mammogram

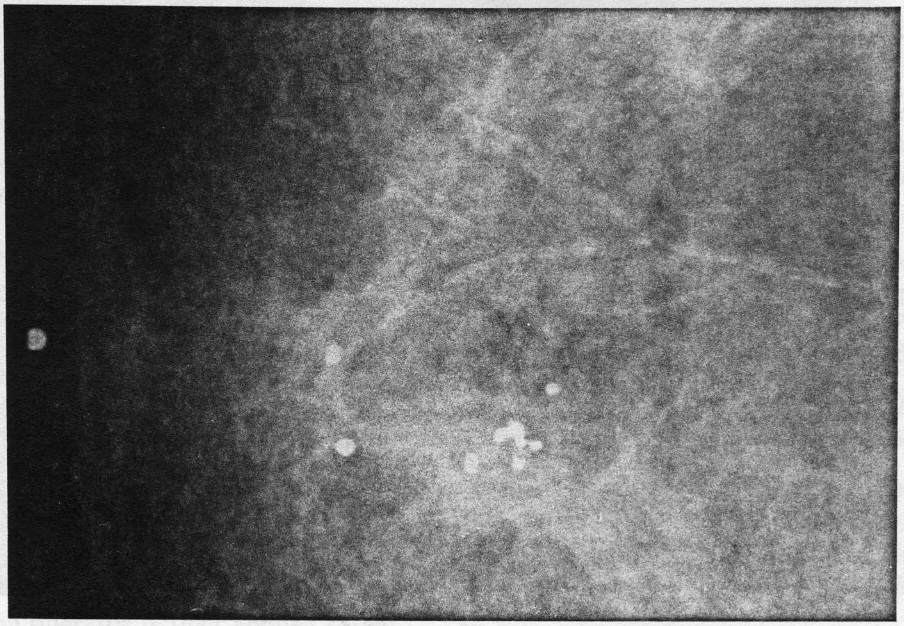

Figure 3: The Original Mammogram

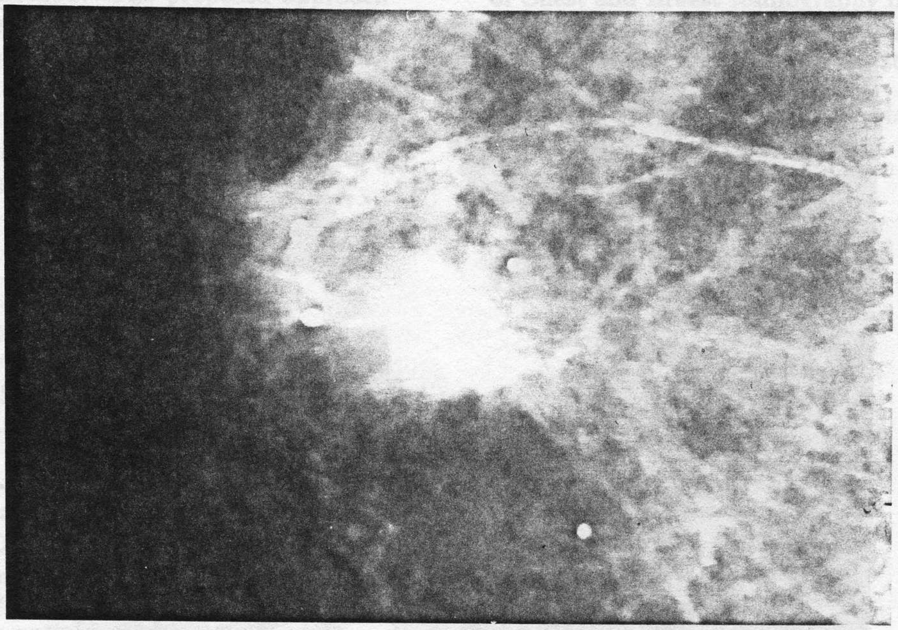

Figure 4: The Enhanced Mammogram

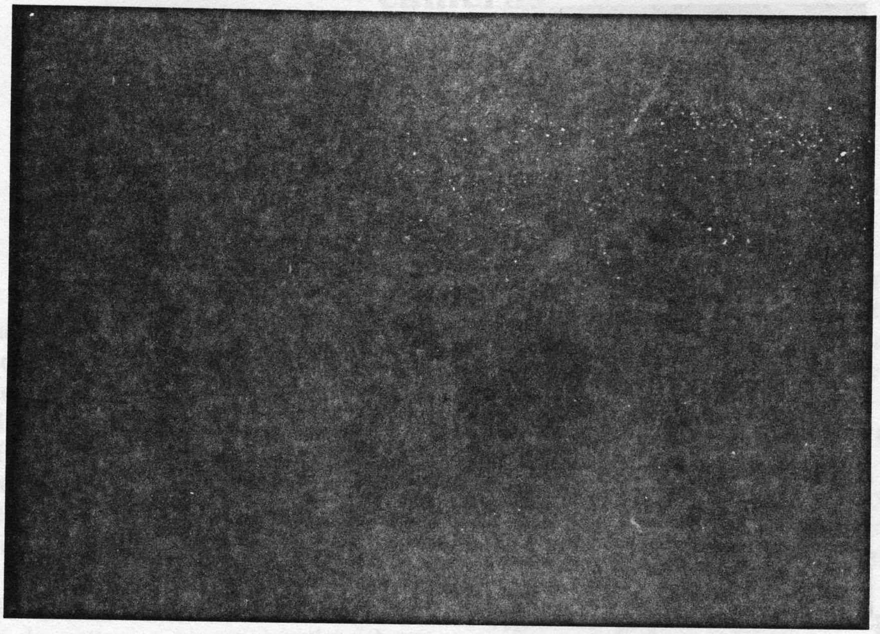

Figure 5: The Original Mammogram

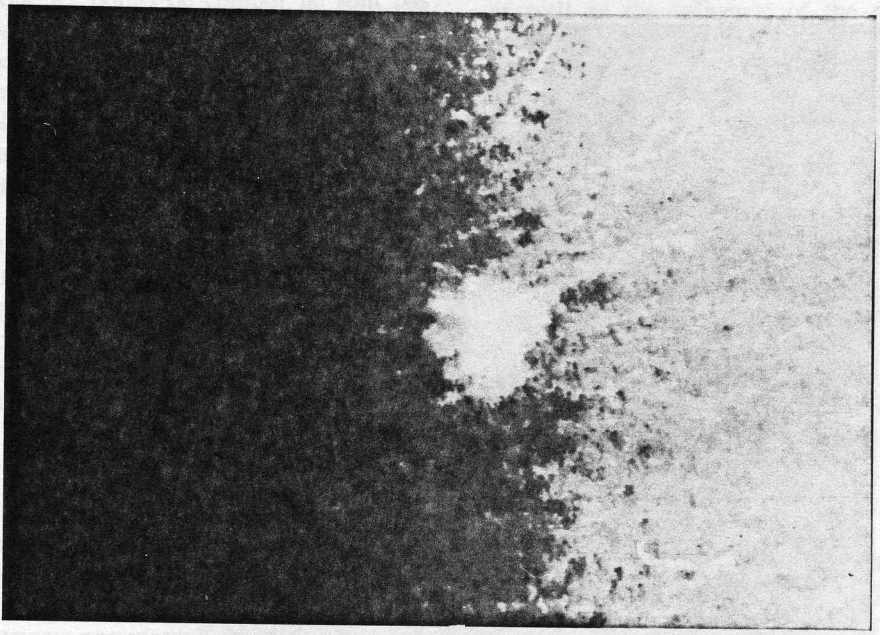

Figure 6: The Enhanced Mammogram

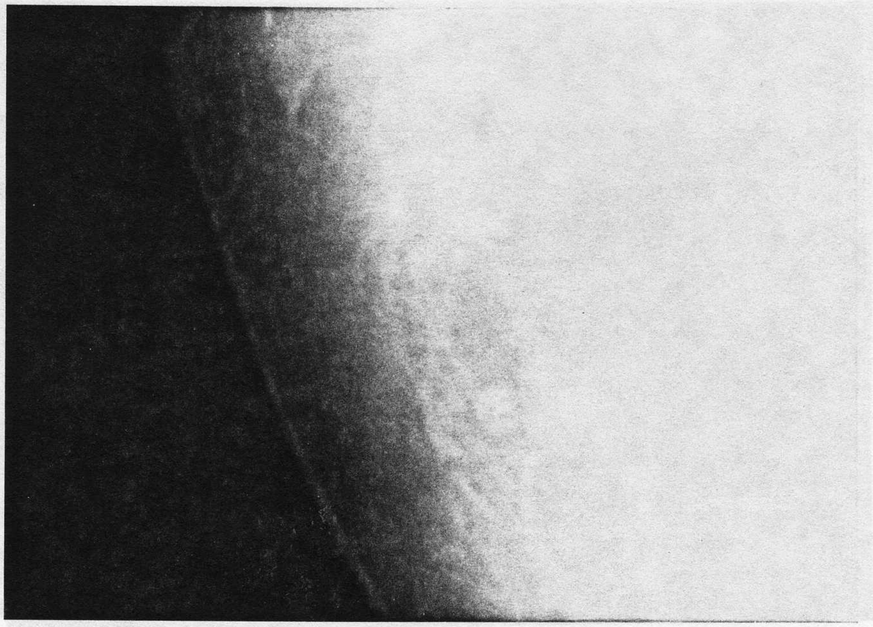

Figure 7: The Original Mammogram

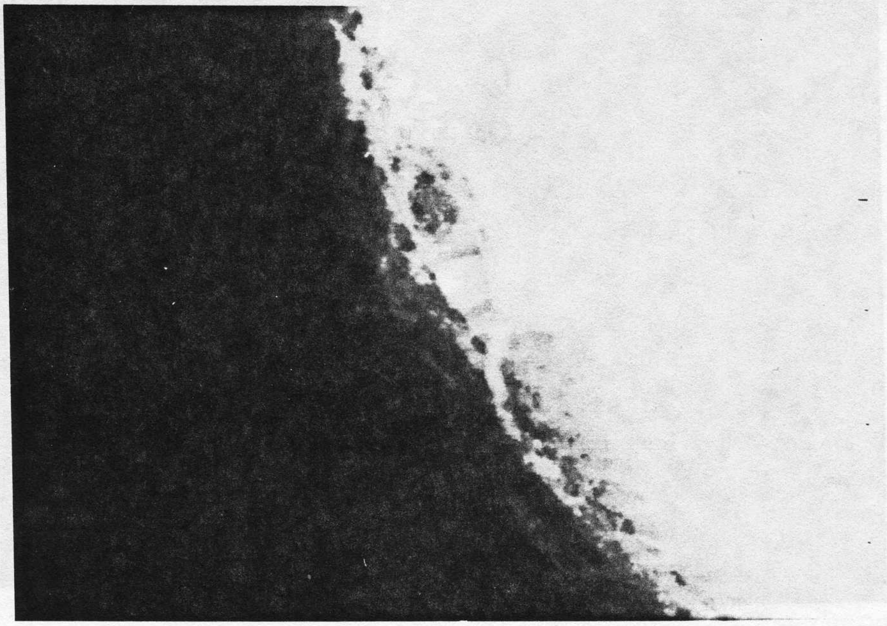

Figure 8: The Enhanced Mammogram