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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report No. 32-1028

Digital Computer Processing of X-Ray Photographs

R. H. Selzer

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November 15, 1966

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Digital Computer Processing of X-Ray Photographs

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Approved by:

J. J. Paulson, Manager
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ABSTRACT

The interpretation of medical and biological pictures, such as x-ray photographs, can frequently be made easier if selected portions of the image are first enhanced by means of a digital computer. Two particular enhancement methods are described in this Report. The first method uses image subtraction to achieve enhancement by removing unimportant information from the picture. The second method uses two-dimensional filtering to achieve enhancement by emphasizing selected portions of the picture frequency spectrum. This filtering method is particularly useful for bringing out fine detail that is totally invisible on the unprocessed picture. Examples of enhanced medical x-rays, photomicrographs, and infrared photographs are shown.

AUTHOR

I. INTRODUCTION

For a number of years, digital computers have been used at Jet Propulsion Laboratory to correct various photometric, geometric, and frequency response distortions in the pictures received from the television cameras of the *Ranger*, *Mariner*, and *Surveyor* spacecraft (Ref. 1). Early in 1966, an investigation began into the applicability of these computer methods to medical and biological photographs, and the initial results of this investigation are presented in this paper.

Broadly speaking there are two types of processing that can be performed by a digital computer on a picture. With the first type, which might be called content analysis, the computer extracts information from the picture and presents the resultant information, nonpictorially in most cases. An example of this type is a pattern recognition system in which the output from the processing consists of an indication of which patterns were present (Refs. 2-5).

The second type of picture processing, and the type described in this paper, might be termed image enhancement (Refs. 6 and 7). The objective is an improved picture—improved in the sense that a human photointerpreter can more readily find what he is looking for. This does not necessarily mean that the picture is better photometrically. The photointerpreter may want lower resolution than he began with or he may want a picture with a highly distorted frequency spectrum, depending

upon the type of picture information he needs and the type he may get. The purpose of this Report is to illustrate some of the things that computer processing can do with a picture so as to better display its information.

After a brief discussion of the scanning system, an explanation is given of a subtraction technique that provides image enhancement by ridding the picture of useless information. The computer provides the flexibility to perform subtractions not possible by conventional methods. Following that, a filtering method is described that allows the Fourier frequency spectrum of the picture to be arbitrarily changed to enhance particular types of data.

II. SCANNING SYSTEM

Medical x-ray photographs are converted into a form suitable for input to the computer by means of a cathode-ray tube scanner. A light beam is passed through a transparency on a line-by-line basis, converted to an electrical signal, and then digitized to a number between 0 and 63, depending upon the optical density of the transparency at the sampled point. Each sample (typically 500,000 samples for a 1-in.-sq transparency) is recorded on magnetic tape which is subsequently fed into an IBM 7094 computer.

In the past, the largest transparency that could be scanned was 35 mm. Although the system is currently being modified to scan 70 mm films, most medical x-ray pictures will still have to be photographically reduced before scanning takes place. Since this reduction causes substantial picture degradation, it would be highly desirable to have a system that would directly scan the picture in its original, full size.

After it has been processed by the computer, the picture is converted back into a transparency by means of the cathode-ray tube scanner. Each sample is converted from digital form to an analog voltage which is used to modulate the intensity of an electron beam as it exposes film by a line-by-line scan.

III. SUBTRACTION

The technique of subtraction of two x-ray pictures taken at different times, as a means of emphasizing change, is not new (Refs. 8 and 9). The usefulness of the technique when accomplished by optical methods, however, is limited because of the difficulty of obtaining two pictures with identical orientation. Closely matched pairs of skull x-rays are not difficult to obtain, but matched chest pictures may be difficult to obtain since small differences in the respiratory cycle will cause considerable differences in the rib position. However, through the use of a distortion-correction program originally developed for application to the cameras of the *Ranger* spacecraft, two mismatched x-ray photographs may be forced into a match and a subsequent subtraction performed.

Geometric distortion in the *Ranger* camera was measured simply by photographing a rectangular screen as

shown in Fig. 1. Distortions, expressed in terms of a point displaced from its true position some number of samples up or down, right or left, were measured at about 100 points on the picture. Subsequent pictures were then corrected by moving samples at the 100 corresponding, measured points to their true position and by moving all intermediate samples proportionately, using linear interpolation. Figure 2 shows the calibration picture after the distortion removal program.

Now consider the application of this program to the pair of chest x-rays shown in Figs. 3 and 4. Figure 3 was taken February 1954 and Fig. 4 on September 1954. Note the appearance of the cancer (indicated by an arrow) in the later photo.[1] A comparison of the rib positions on the patient's right side in the two pictures shows the mismatch. The results of the correction program, based on measurements of 80 points on the patient's right side, are shown in Fig. 5.

After one picture was distorted to match the other, a subtraction was performed on the two pictures point-by-point. The absolute value of the differences was taken and, after a contrast increase by a factor of four, the results as shown in Figs. 6–9 were obtained. Figure 6 represents the difference picture for the best match that could be obtained strictly by translation and magnification change. Figure 7 represents the same difference after application of the correction program. Note that the cancerous area is more evident on the matched difference.

Since the two pictures were not taken at the same time, it is likely that the conditions for exposure and development were not identical. Thus even a perfect geometric match of a physiologically unchanged area might still produce a difference that is not zero. For example, the first picture, labeled 2/54, was substantially darker on the patient's right side than the other picture, but was lighter on the left side.

To minimize the effect of such differences, a high-pass filter (discussed in detail in the next section) was first applied to the pictures. This tended to decrease background variation between the two pictures. Figure 8 shows the filtered version of the picture labeled 9/54. This should be compared with the unfiltered version in Fig. 4. Figure 9 shows the difference picture where negative differences were set to zero (*white*). A comparison of the right half of Figs. 8 and 9 shows how the total information in a picture can be substantially reduced by removing information of low interest.

[1]Noted by William Weiss, MD, on a drawing that accompanied the original chest x-ray photographs.

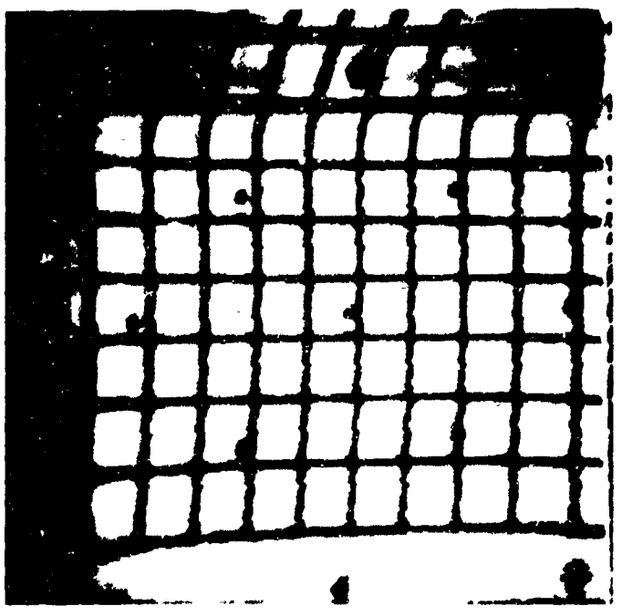

Fig. 1. *Ranger 3* calibration picture before distortion correction

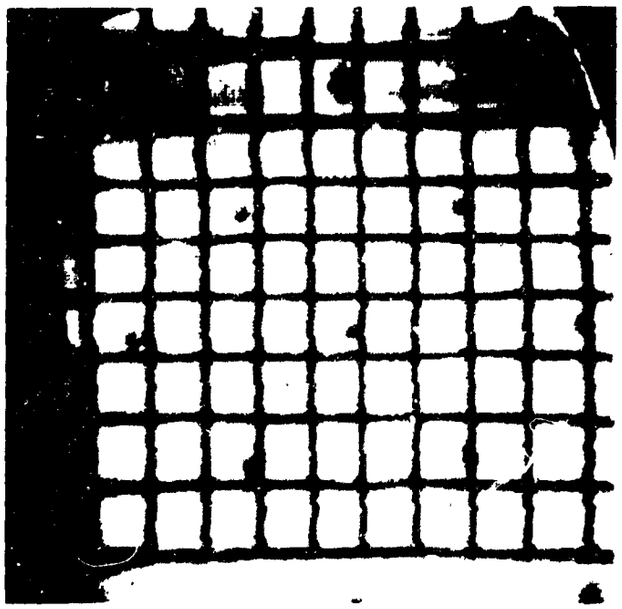

Fig. 2. *Ranger 3* calibration picture after distortion correction

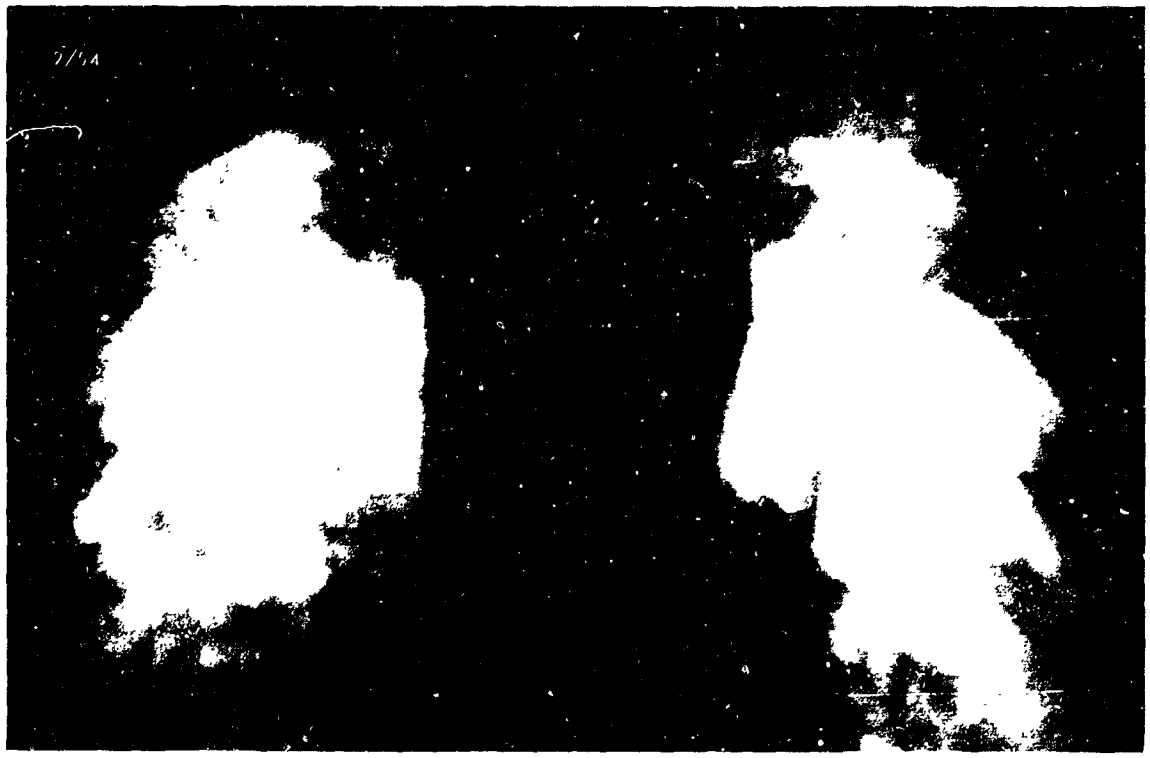

Fig. 3. X-Ray of chest taken February 1954

Fig. 4. X-Ray of chest taken September 1954, showing cancer *(arrow)*

Fig. 5. X-Ray of chest taken September 1954, after application of correction program to match earlier x-ray

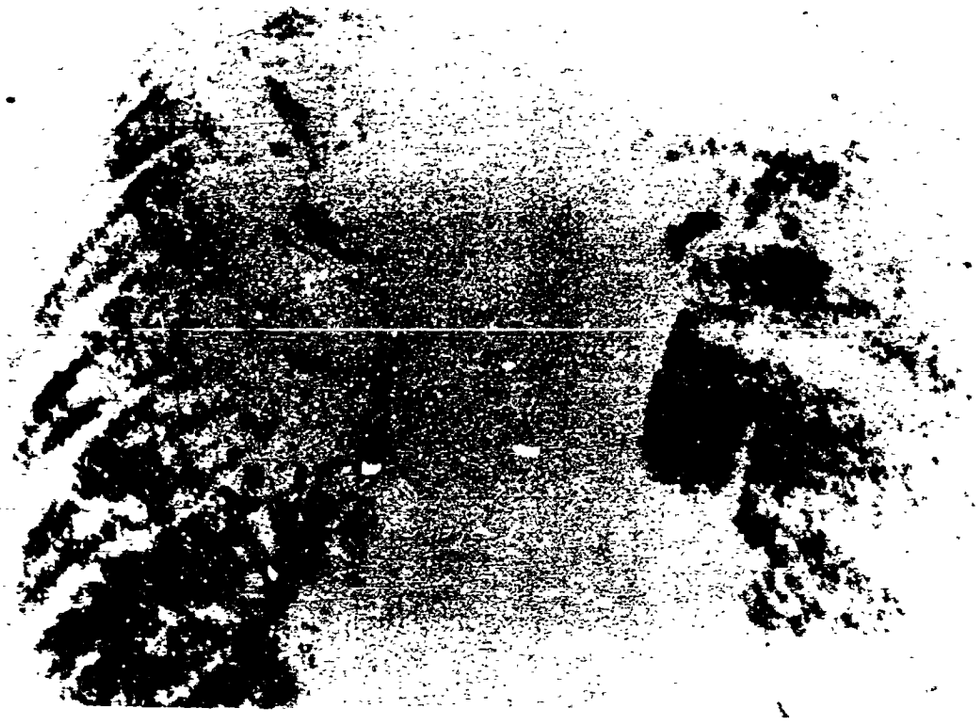

Fig. 6. Absolute-difference picture without correction program

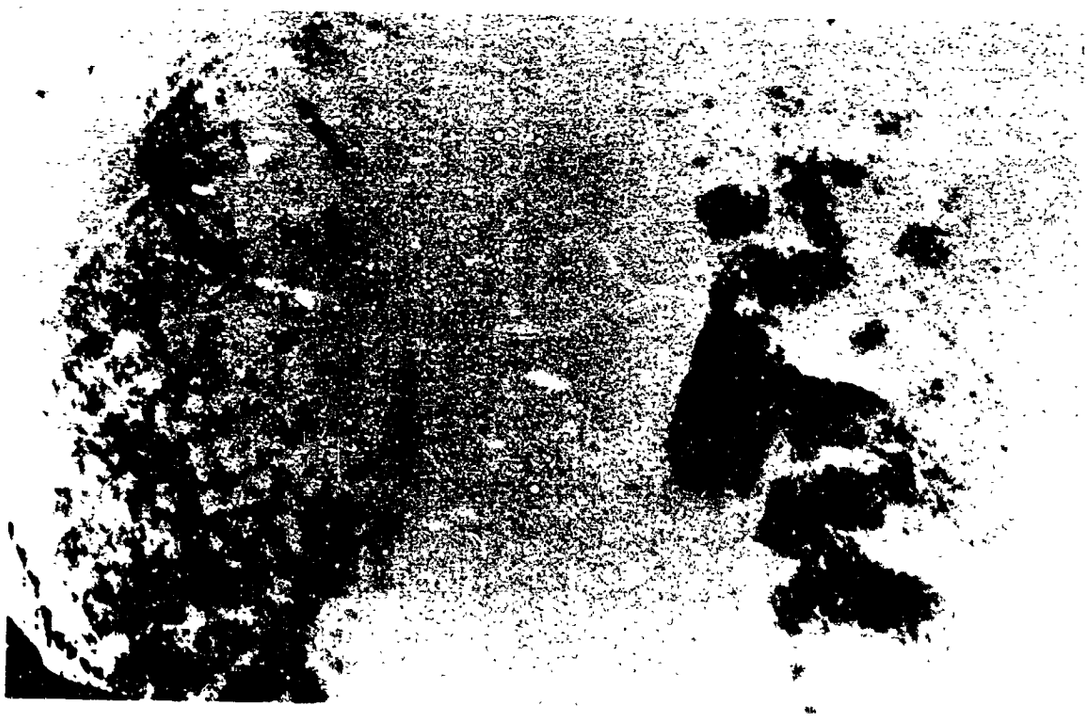

Fig. 7. Absolute-difference picture after correction program

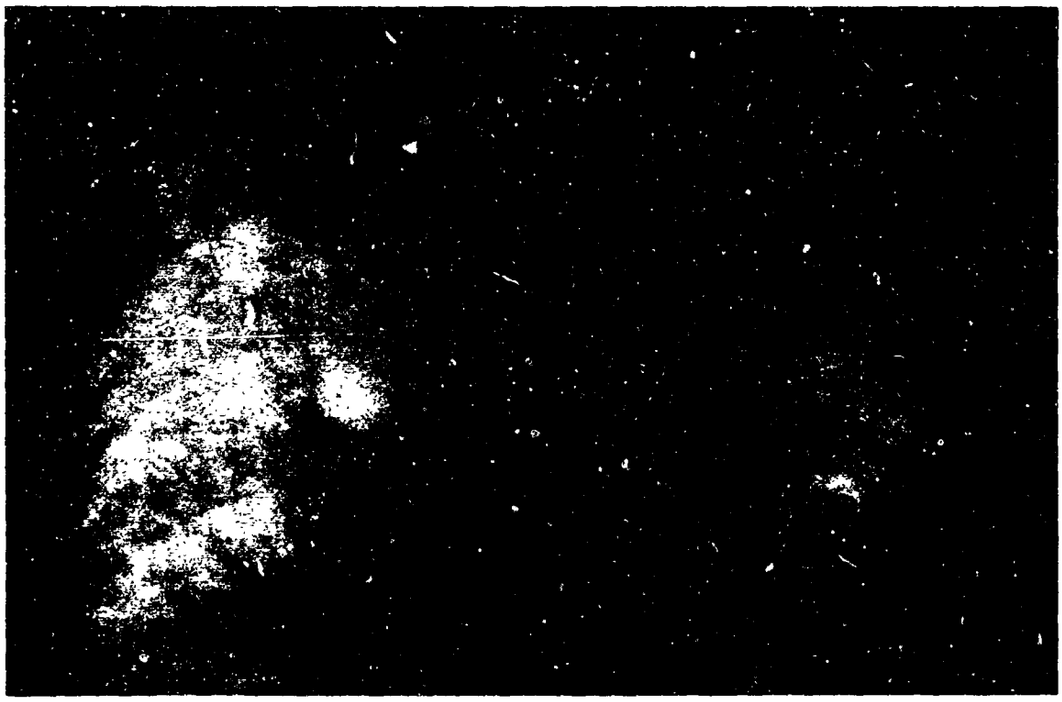

Fig. 8. X-Ray of chest taken September 1954, after high-pass filter

Fig. 9. Result of subtracting chest x-ray of February 1954 from x-ray of September 1954 and setting negative differences to zero *(white)*

IV. FREQUENCY-RESPONSE ENHANCEMENT

The second image-enhancement technique to be described uses two-dimensional digital filters to effectively modify the frequency spectrum of the picture. Considerable attention has been devoted to measuring the frequency response of x-ray systems in terms of the modulation transfer function, which gives the relative response of the system as a function of spatial frequency in cycles per millimeter. A typical modulation transfer function of an x-ray system is shown in Fig. 10(a). The high-frequency falloff is caused by a number of factors that have been extensively studied. For example, the random distribution of x-ray quanta on a fluorescent intensifying screen causes a mottled effect that decreases system resolution. Similarly, the non-zero width of the x-ray source causes a high-frequency loss because of a penumbra effect. Loss may also be due to numerous other causes, such as diffusion and bounceback in intensifying screens, film graininess, and radiation scatter.

As indicated in Fig. 10(a), the higher the frequency of the pictorial information, the lower the relative amplitude. At some frequency, this amplitude becomes so small relative to the background noise—which is more or less independent of frequency—that the picture signal is irretrievably lost. However, just below this frequency there often exists picture information that is invisible because of its low amplitude but which *is present* in the picture and is recoverable.

The recovery method is based on the use of a digital filter whose transfer function, shown in Fig. 10(b), is the reciprocal of the modulation transfer function of the x-ray system. The resultant overall system transfer function is then, as shown in Fig. 10(c), essentially flat out to some cutoff frequency. The cutoff frequency chosen is the highest possible without undue emphasis on background noise.

A sample is digitally filtered by calculating a weighted average of the surrounding samples—the weights determining the effective filter transfer function. In turn, the weights are determined by sampling the Fourier Transform of the desired transfer function, an example of which is shown in Fig. 10(b). An infinite number of weights gives the exact filter transfer function and a truncated series gives an approximation. All of the pictures to be discussed were filtered by a 15-by-15 array of weights which were generally sufficient to produce a filter to within one percent of that desired.

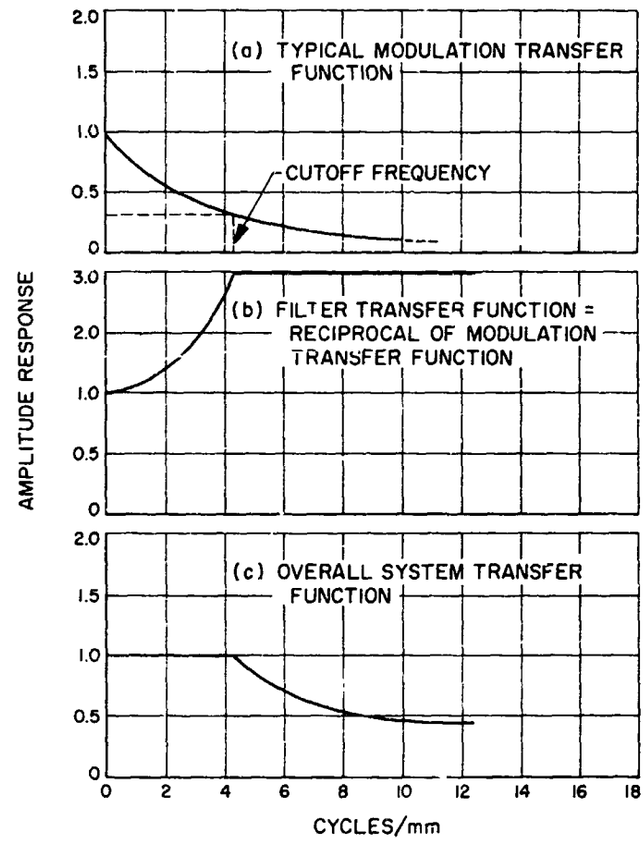

Fig. 10. Effect of filter on system transfer function

Figures 11 through 16 show examples of filtered pictures. The first is a skull x-ray showing the unprocessed picture in Fig. 11 and the filtered picture in Fig. 12. A general sharpening of the image is shown. Similarly, an infrared photograph of a diseased foot in Figs. 13 and 14, and a microscope photograph of a chromosome in Figs. 15 and 16 show the improvement in resolution after filtering.

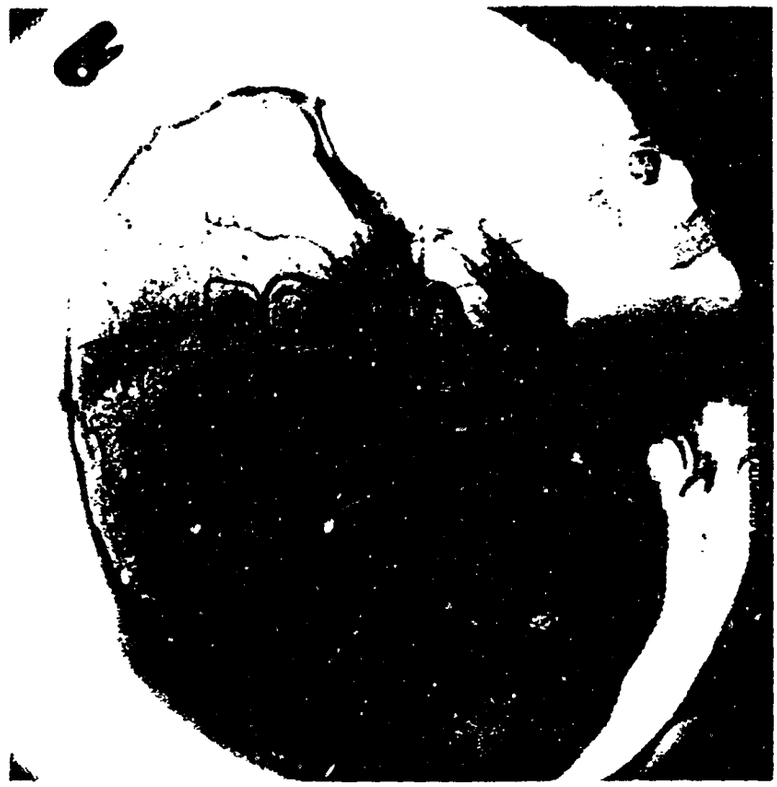

Fig. 12. Angiogram of skull after high-frequency emphasis filter

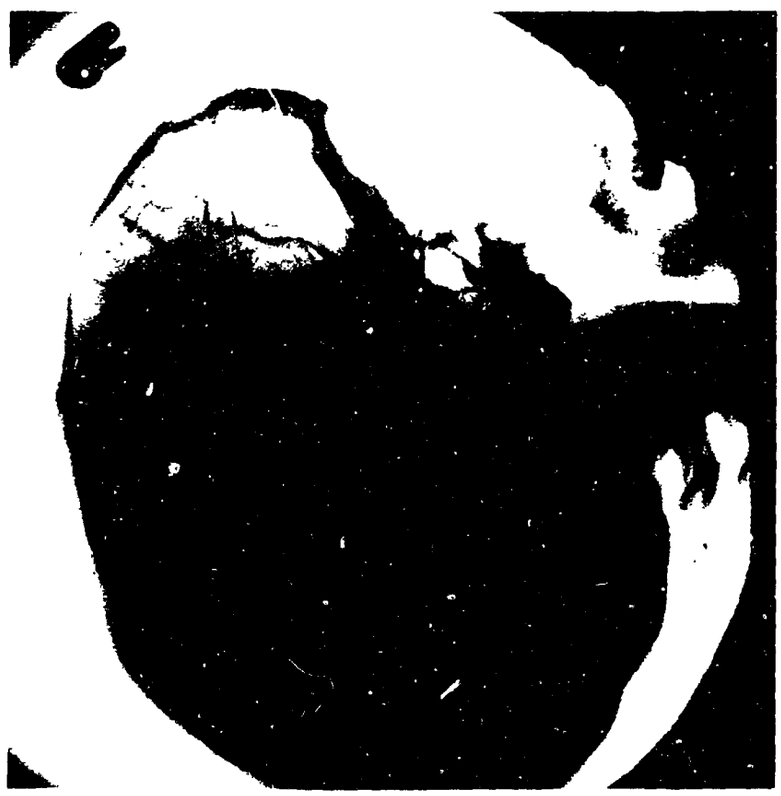

Fig. 11. Angiogram of skull before filtering

Fig. 14. Infrared photograph of diseased foot after high-frequency emphasis filter

Fig. 13. Infrared photograph of diseased foot before processing

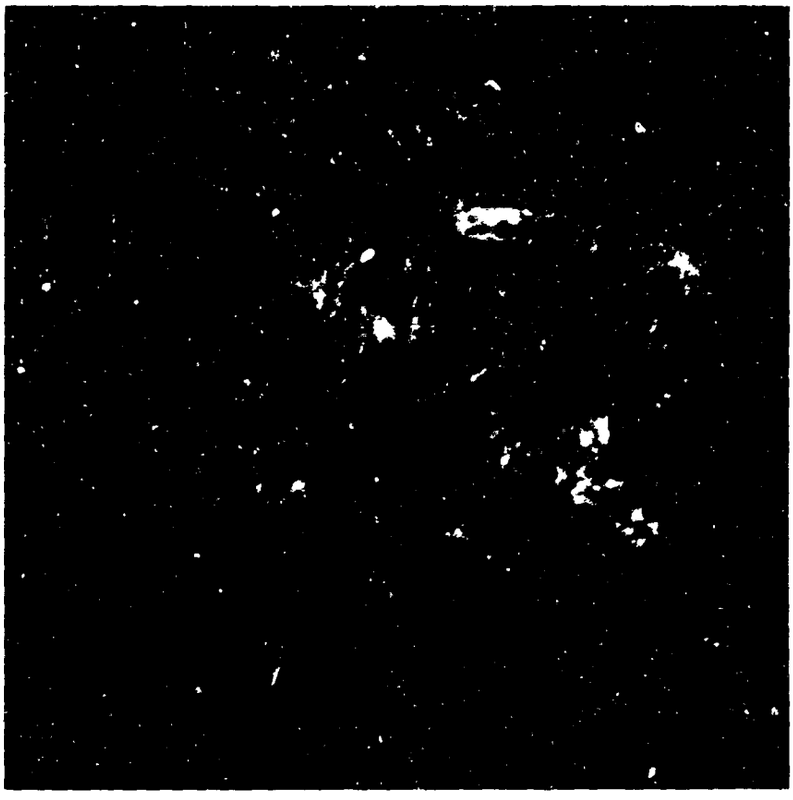

Fig. 15. Photomicrograph of chromosome in metaphase, before processing

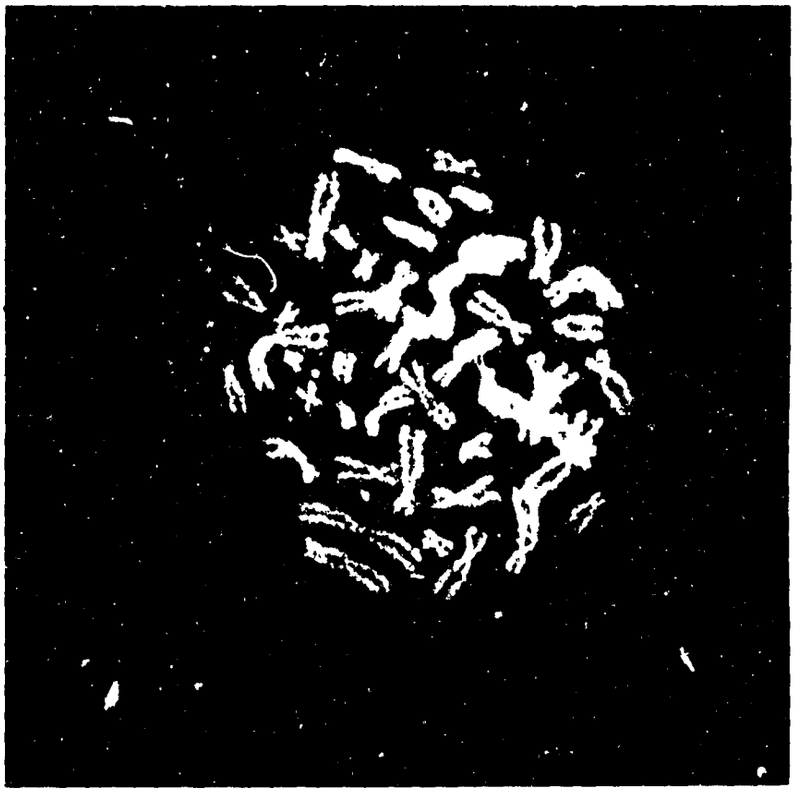

Fig. 16. Photomicrograph of chromosome in metaphase, after high-frequency emphasis filter

A better insight into the way in which the high-frequency emphasis filter works can be obtained by viewing the process as a high-pass filter, as shown in Fig. 8. The top curve shows a high-frequency signal superimposed on a low-frequency signal. The assumption is that the low-amplitude, high-frequency signal will not be seen against the large dark-to-white excursion of the other signal. Direct contrast enhancement as shown in Fig. 17(b) simply causes loss of the high-frequency signal because of saturation. Instead, as shown in Fig. 17(c), it is necessary first to remove some of the low-frequency signal using a high-pass filter; and then to increase contrast for effectively emphasizing the high-frequency signal.

A rather extreme high-pass filter was applied to the skull x-ray as shown in Figs. 18 and 19. The objective was to bring out the blood vessels lost in the highly exposed frontal portion of the skull. This filter removed all dc signal and a proportion of all low-frequency information. As seen, the frontal blood vessels were clearly enhanced although at the cost of some distortion in the rest of the picture. A less extreme filter, perhaps one that removed three-quarters of the dc signal, would probably accomplish the same objective and, at the same time, maintain more of the original pictorial integrity.

A rather surprising result was obtained when this filter was applied to a mastoid x-ray. The section filtered is shown in Figs. 20 and 21. Figure 21 is a digitized version of the area indicated by the *box* in Fig. 20. Our intent was to bring out the mastoid structure beneath the denser bone toward the front but, as seen in Figs. 21 and 22, the signal-to-noise ratio was too low in this area for us to achieve our objective. However, in Fig. 22 minute detail of the mastoid structure suddenly became visible. This kind of detail could be very useful for detecting the presence of fluid in the cells.

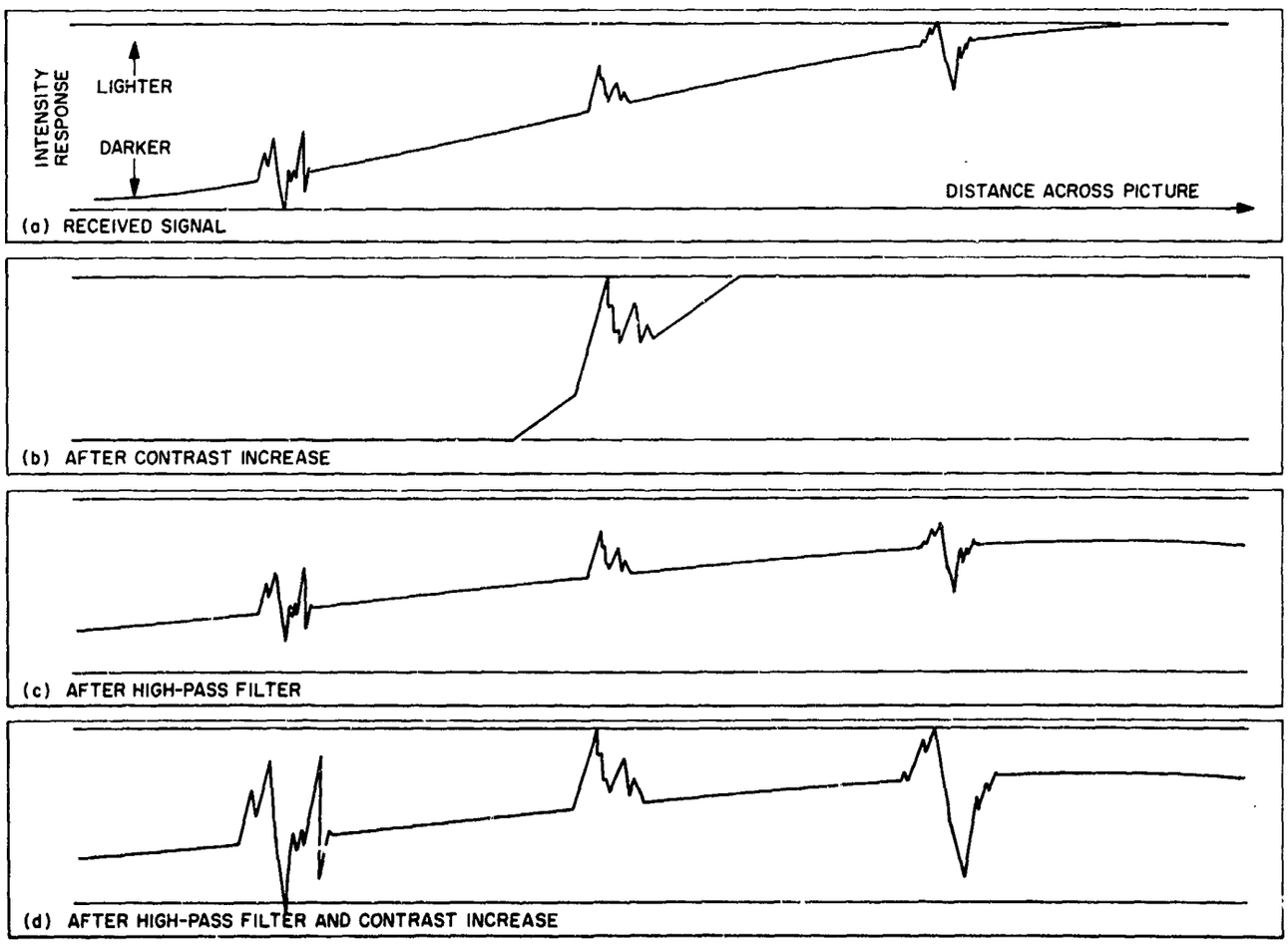

Fig. 17. Effect of high-pass filter

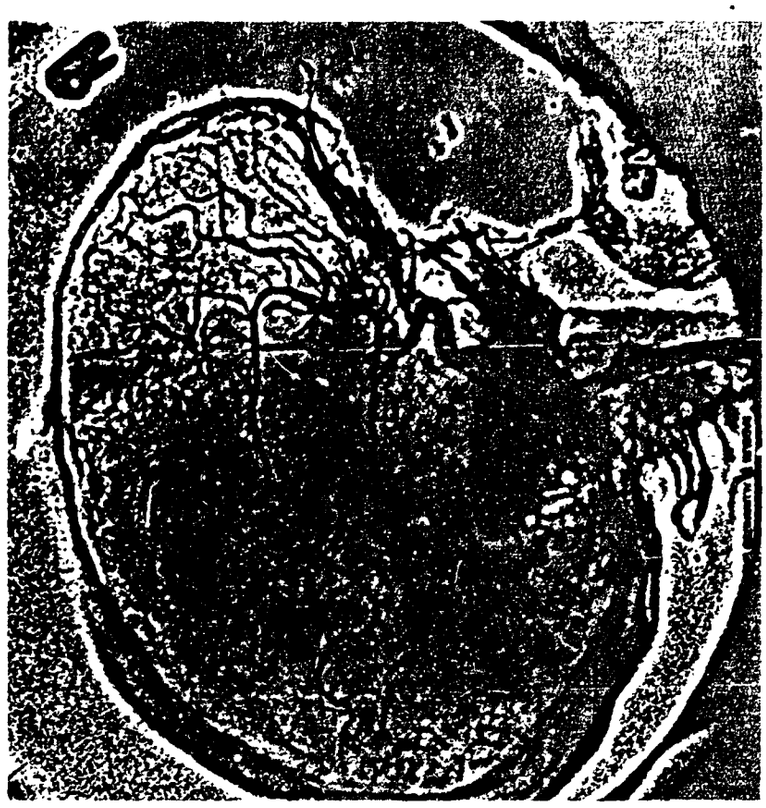

Fig. 19. Angiogram of skull after high-pass filter

Fig. 18. Angiogram of skull before processing

Fig. 20. X-Ray of skull showing portion of mastoid selected for processing (*box*)

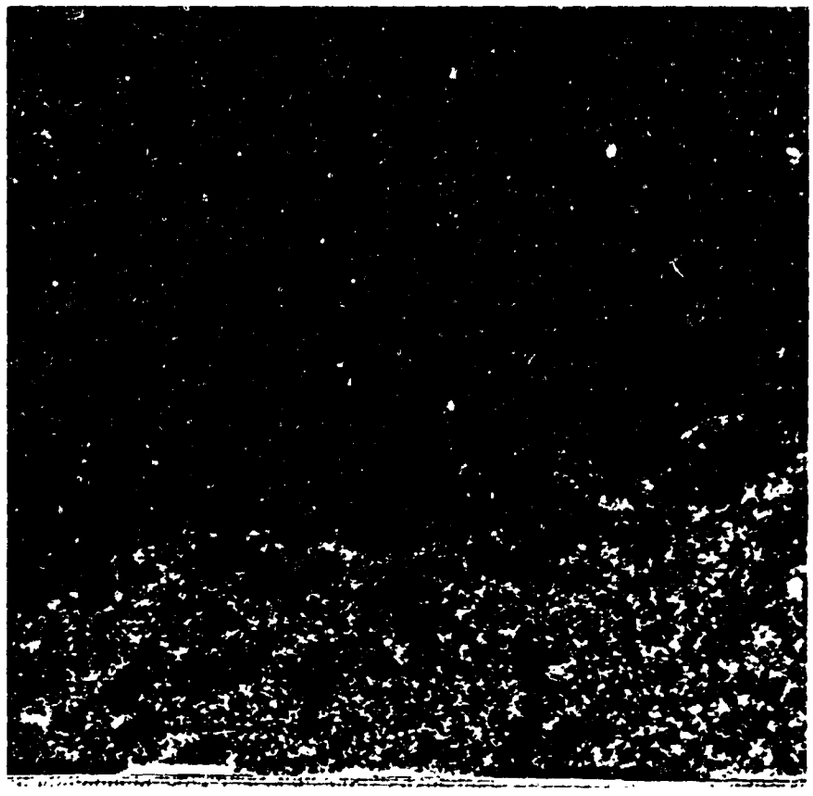

Fig. 22. X-Ray of mastoid after high-pass filtering

Fig. 21. X-Ray of mastoid after digitizing, but before filtering

V. CONCLUSIONS

The purpose of the work to date has been to demonstrate the general capability of the computer to process medical and biological photographs. The next step is to apply these techniques to problems of specific medical value. In addition, a general investigation in the following areas should proceed:

Color work. Processing of color pictures can easily be accomplished by digitizing and processing each color component separately and then recombining components.

Nonsymmetric filtering. Filters with different transfer functions in the horizontal and vertical directions could be extremely useful. For example, a picture of a suspected hairline fracture with a known direction could be enhanced by applying a filter that emphasized low frequencies in the direction of the fracture and high frequencies perpendicular to that direction.

On-line operation. A computer tied directly to a film scanner, and having an instantaneous pictorial display of pictures stored in its memory, could decrease the time required to perform an operation such as subtraction from days to minutes, because a human operator viewing the match could adjust parameters on-line and accomplish the match very rapidly. Such a computer system is currently being assembled at Jet Propulsion Laboratory and should be fully operating early in 1967.

Spectral analysis. To effectively perform image enhancement by filtering, it is necessary to obtain better correlation between subjective visual quantities such as texture or pattern and a quantitative descriptor such as the two-dimensional Fourier spectrum. Thus spectral analysis on many different types of x-ray photos would be desirable.

REFERENCES

1. Nathan, R., *Digital Video-Data Handling*, Technical Report 32-877, Jet Propulsion Laboratory, Pasadena, California, January 5, 1966.
2. Highleyman, W. H., "Linear Decision Functions with Application to Pattern Recognition," *Proceedings of the Institute of Radio Engineers*, vol. 50, pp. 1501–1514, June 1962.
3. Sebestyen, George S., "Recognition of Membership in Classes," *IRF Transactions on Information Theory*, vol. IT-7, pp. 44–50, January 1961.
4. Butler, J. W., Butler, M. K., and Stroud, Agnes, "Automatic Classification of Chromosomes—III," in the *Proceedings of the 1966 Rochester Conference on Data Acquisition and Processing in Biology and Medicine*. Pergamon Press, to be published early in 1967.
5. Lodwick, G., Keats, T. E., Dorst, J. P., "The Coding of Roentgen Images for Computer Analysis as Applied to Lung Cancer," *Radiology*, vol. 81, no. 2, August 1963.
6. Meyers, P. H., et al., "Evaluation of a Computer-Retrieved Radiographic Image," *Radiology*, vol. 81, no. 2, pp. 201–206, August 1963.
7. Potsaid, M. S., Swanlund, C. D., King, G. E., and Neuberger, A., "Computer Analysis of Radiographs," *Lippincott's Medical Science*, vol. 17, no. 3, pp. 35–43, March 1966.
8. Hanafee, W., and Stern, P., "Subtraction Technic," *Radiology*, vol. 79, no. 4, pp. 658–661, October 1962.

REFERENCES (Cont'd)

9. Ludovico, N., "Subtractive Interference Technique in Radiography," *Radiographia*, no. 8, pp. 169–185, March 1964.

10. Morgan, R. H., Bates, L. M., Gopalarao, U. V., and Marinaro, A., "The Frequency Response Characteristics of X-Ray Films and Screens," *The American Journal of Roentgenology, Radiation Therapy and Nuclear Medicine*, vol. 92, pp. 426–440, August 1964.

11. Morgan, R. H., "The Frequency Response Function," *The American Journal of Roentgenology, Radiation Therapy and Nuclear Medicine*, vol. 88, no. 1, pp. 175–186, July 1962.

12. Rossman, K., "Spatial Fluctuations of X-Ray Quanta and the Recording of Radiographic Mottle," *The American Journal of Roentgenology, Radiation Therapy and Nuclear Medicine*, vol. 90, no. 4, pp. 863–880, October 1963.

13. Holm, Thure, "Some Aspects of Radiographic Information," *Radiology*, vol. 83, no. 2, pp. 319–327, August 1964.

14. Rossman, K., "Modulation Transfer Function of Radiographic Systems Using Fluorescent Screens," *Journal of the Optical Society of America*, vol. 52, no. 7, pp. 774–777, July 1962

15. Rossman, K., "Image-Forming Quality of Radiographic Screen-Film Systems; The Line Spread-Function," *The American Journal of Roentgenology, Radiation Therapy and Nuclear Medicine*, vol. 90, no. 1, July 1963.

APPENDIX

Because of space limitations, not all of the pictures that were contributed for processing could be incorporated into this Report. However, since all of the submitted pictures were extremely helpful in the establishment of the computer techniques, they have been included in the list below.

X-Rays (single frames)

Osteoporosis in the knee.	Donald Deselits, MD, Department of Radiology, University of California, Los Angeles
Chest cancer.	William Weiss, MD, Director, Philadelphia Pulmonary Neoplasm Research Project
Aortic aneurysm.	C. Murphy, MD, George Washington University Hospital, Washington, D.C.
Skull circulation.	Amos Norman, PhD, Department of Radiology, University of California, Los Angeles
Polytone ear pictures.	Joseph L. Westover, MD, Department of Radiology, University of California, Los Angeles

X-Rays (moving pictures)

Heart circulation.	Russell H. Morgan, MD, Johns Hopkins Hospital, Baltimore

Gamma Rays

Lung cancer, Scan Method.	W. Tauxe, MD, Mayo Clinic, Rochester

Infrared Photography

Diseased foot.	David Bendersky, BSME, Head Engineer, Mechanical Section, Midwest Research Institute, Kansas City, Missouri

Photomicrograph

Chromosomes.	Amos Norman, PhD, Department of Radiology, University of California, Los Angeles

Direct Photography

Retina tumors.	Herman Weiss, MD, Ophthalmologist, Beverly Hills, California

ACKNOWLEDGMENT

This work was done in collaboration with Dr. Robert Nathan of Jet Propulsion Laboratory and with the encouragement of the NASA Technology Utilization Division. The author would also like to thank those persons listed in the Appendix who provided photographs for processing.