# Digital Image Enhancement of Cephalograms

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Since 1931 when roentgenographic cephalometry was introduced as a standardized radiographic technique,[1] there have been many thousands of radiographs, perhaps millions, taken for various purposes. These radiographs are of interest to dentists (primarily orthodontists), anthropologists, pediatricians, maxillofacial and plastic surgeons. The uses for these radiographs range from the diagnosis of jaw malposition, evaluation of orthodontic and/or surgical intervention, to the analysis of growth and development. The historical aspects of the development of the techniques in the study of the human head are well-documented[2,3] and, in summary, follow a sequence from craniometry (measurements of skulls) to cephalometry (the measurement of the head with overlying soft tissue) and finally to roentgenographic cephalometry where measurements are derived from tracings of the X-ray film.[4] The introduction of roentgenographic cephalometry provided the foundation for longitudinal studies by enabling objective measurements of the craniofacial changes of an individual over a period of time. These changes may also be brought about by orthodontic or surgical intervention and thus therapeutic measures may be evaluated. Standards of normal craniofacial growth are necessary by which these evaluations can be compared. Several longitudinal and cross-sectional series of cephalograms have been accumulated. The analyses of these radiographs have included several methods, each with its own set of "appropriate" points, lines, and angles devoted toward their specific needs. Recent efforts, however, have been cognizant of the dynamic aspects of craniofacial growth and the structures that have been selected for growth evaluations have been chosen from a functional frame of reference.[5] The quantification of these points of measurements has relied on tracings derived by visual examination and subsequent drawings on transparent acetate sheets. A fundamental belief in using this procedure is that these points can be readily identified and that the tracings can be accurately reproduced. Measurements derived from these tracings are thus dependent upon the accuracy of the tracer. Measurement errors can thus arise from two sources. First will be the errors in tracing and secondly, those arising from the measurement itself.

The large number of radiographs that have been accumulated by several institutions during the past years are a source for establishing base lines of normal growth and development. However, for these norms to have any validity, extensive and accurate analyses must be computed to establish statistics, such as means and variances for each variable by age, sex, race, etc. This will require voluminous data, thus a more rapid form of quantification is necessary. To meet this requirement an interactive digitizing system was developed[5,6] whereby skeletal structures of the skull from the lateral view are mapped. Each point on the skull has a specific X-Y coordinate which is mapped in a sequential manner. The lateral radiograph is first traced to record the outline of the bone, then the points to be recorded are marked or digitized. Finally the digitized tracing

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is placed on a device to record the points as X-Y coordinates. This method has greatly facilitated the analysis of cephalograms since direct input to a digital computer is now possible to establish a large data base. The data can then be manipulated via written programs to retrieve information to establish developmental norms, predict growth, and simulate changes in shape and size of the craniofacial structures. The techniques of roentgenographic cephalometry are thus entering another phase by using advanced technology in electronics and computer science. The basis for data is the radiograph and, at the present time, hand-tracings are still utilized and remain a major bottleneck for rapid and accurate analysis of cephalograms. One technique which may solve the problem is digital image enhancement.

Digital image enhancement has been used in many fields and is most familiar to the public as the restored and enhanced images telemetered to earth from space explorations, most recently by the Viking mission to Mars. These images were "computer restored" or "computer rectified" and the results were seen by the public.[7] The same techniques have been applied to medical radiographs, notably chest radiographs[8] and angiograms.[9,10] The basic principles involved in the enhancement of radiographs by a digital computer have been presented elsewhere,[11,12] and only a summary will be presented here.

Image *enhancement* differs from image *restoration*. In the latter an ideal image is reconstructed from a poor image. This is akin to what one attempts when an aged or faded photograph is restored to as near the original condition as possible. Digital image restoration attempts to eliminate imperfection in an image so that the final result will be as if the image were taken under optimum conditions with a perfect optical system. Examples are corrections of blurs created by camera movement or an out-of-focus lens. Digital image restoration implies that one knows exactly how the original image deviated from the ideal. Digital image enhancement differs from restoration in that there are no assumptions on the deviation from the ideal but realizes only the details that are to be clarified in the final image. Thus, the enhanced image formed by use of various techniques may have contrasts that are quite unlike the original image although the resultant features will now stand out in greater detail.[12] This is the technique that is most adaptable for radiographs and is described here for the cephalogram. A universal enhancement technique is not possible since the requirements for each type of radiograph will differ; however, techniques are available for each specific problem. For example, the requirements for bringing forth soft tissue structures are quite different than for skeletal tissue since the densities are not the same.

Certain basic hardware is needed for digital image enhancement. A diagram illustrating the procedures used for enhancing is illustrated in Figure 1. The original image is first scanned by one of many types of devices to convert the values of radiographic density to a series of numbers and store them on some device, e.g., magnetic tape. The values of density are measured on a regular two-dimensional grid of points and the stored values are used as input data to a suitable program within the digital computer. Following computer enhancement, new data are written containing the output image. These data are used as the input to the display hardware on which the enhanced image is produced. The display hardware can take many forms from a video system, a computer output microfilm device, to a film output device similar to the origi-

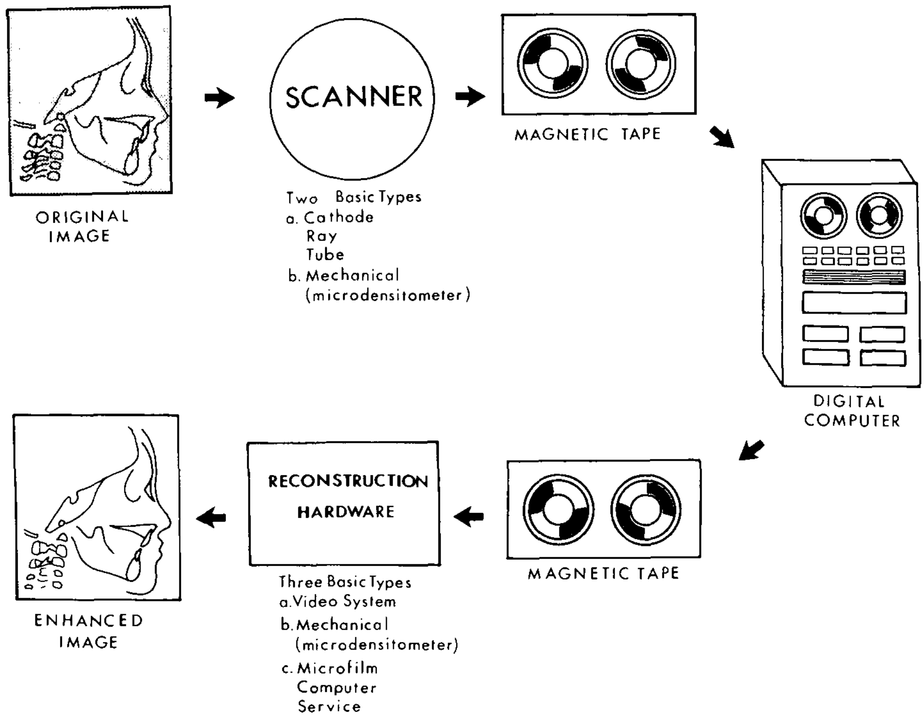


Fig. 1 Generalized flow diagram for digital image enhancement.

nal microdensitometer film scanner. The enhancement work described in this paper was done at the Los Alamos Scientific Laboratory.

The radiograph selected for the enhancement procedure (Fig. 2) is of poor quality since it displays a relatively homogeneous density of the skeletal structures. Although a portion of the reduction in the quality of the radiograph is due to reproduction on photographic paper, the selection of this less than optimum radiograph was purposeful to illustrate the power of the digital enhancement technique in its ability to clarify structures not visible to the naked eye.

The original lateral cephalogram of a young male (Fig. 2) was scanned on a flatbed X-Y microdensitometer with a square aperture 100 microns on a side. The spacing between samples was 160 $\mu$. The resulting computer image was a 1000 $\times$ 1000 matrix of film density values. This matrix is transformed by a two-dimensional Fourier transform. This gives a 1000 $\times$ 1000 matrix of coefficients in the spatial frequency domain. Each coefficient represents the contribution to the original density signal made by a complex sine wave of a specific frequency. In a medical X-ray the coefficients representing lower spatial frequencies are dominant because of the characteristic presence of large areas of similar densities. The coefficients for higher spatial frequencies contain detail and edge information; since medical X-rays rarely display sharp edges or great detail, these coefficients are characteristically of much lower magnitude than those corresponding to lower frequencies.

The first step in the enhancement procedure is to boost the energy in the higher frequencies, i.e., multiply the

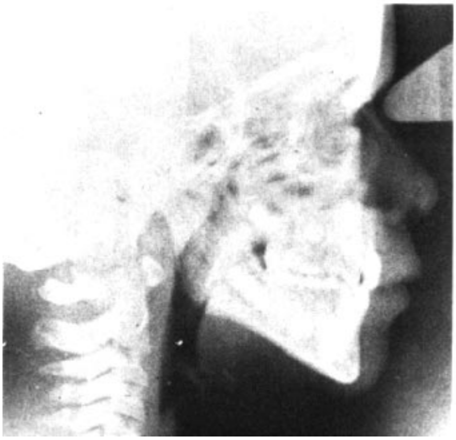

Fig. 2 Standard cephalogram prior to image enhancement.

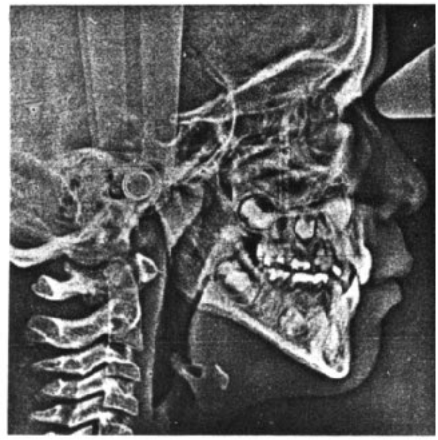

Fig. 3 Enhanced image of Figure 2.

higher frequency coefficients by terms whose magnitude is greater than 1.0, and attenuate the energy in the lower frequencies, i.e., multiply by terms whose magnitude is less than 1.0. The filter function used has the form 2.0 [1.0-exp(—2.0 f)] where f is spatial frequency in cycles per millimeter. The image is then transformed back to the spatial domain. The effect of this filtering is to increase the energy of the detail information at the expense of the over-all gray tone of the image. The processed image at this point appears rather "flat" with edges readily apparent but without much tone.

The second step is to increase the contrast of the filtered image. The method used here is histogram equalization. The histogram in the spatial domain is an estimator of the probability density function. Histogram equalization attempts to reassign densities so that each density value occurs with equal probability. This procedure maximizes the information theoretic entropy measure, $\Sigma\ p_i \log p_i$, where $p_i$ is the probability that the $i^{th}$ density value will occur. The visual result is to increase the contrast of the image by spreading the histogram.

The resulting enhanced image has much better defined edges and small details are more easily seen. Dimensional measurements can now be made with much improved accuracy. Measurements of film density have been rendered meaningless by this type of enhancement. Experience has shown this method to give good results with a minimum of artifacts. The results shown in Figure 3 represent standard processing with no tailoring to that specific image.

Presently, image enhancement is performed in institutions with access to a large computer supporting sophisticated peripheral hardware including bulk storage and supplemental magnetic core. Installations of this type are beyond many medical institutions; however, development of specific software for implementation on minicomputers is possible and will be readily available in the near future. A system such as this developed specifically for enhancing standard radiographs will be of value for diagnostic and research purposes and one which can also be utilized as a preprocessor of radiographs for any future fully-automated mensurational scheme.

SUMMARY

Quantification of cephalometric X-rays requires the use of hand tracings of the structures to delineate points, lines, and angles. The structures, especially soft tissue, are often obscure and are therefore approximated. Recent biomedical application of image enhancement by digital computer promises a method whereby landmarks in the cranium are more clearly defined. Development of this technique will enable a more extensive and accurate utilization of cephalometric radiographs for diagnostic and research purposes.

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