Ann. Bull. RILP, No. 9, 1-14 (1975)

TONGUE PELLET TRACKING AND OTHER RADIOGRAPHIC OBSERVATIONS BY A COMPUTER CONTROLLED X-RAY MICROBEAM SYSTEM

By S. Kiritani, K. Itoh, H. Imagawa, H. Fujisaki and M. Sawashima

In our last Annual Bulletin, we reported the completion of the high voltage x-ray microbeam system.[1] The system is now in operation and an experiment on automatic tracking of several pellets on the tongue has been conducted.[2), 3)] Also, some pilot experiments have been conducted exploring applications of the present method to other radiological observations. This report will present some early data gathered in these experiments.

During the past year, intensity of the x-ray beam has been increased by improving the x-ray generator adjustments. At present, the maximum rating of the x-ray generator is 150kV-2mA and the photon density in the x-ray beam(1 mm in diameter on the object plane) is 2×10^7 per second approximately, with a Cu filter of 0.6 mm in thickness.

Image Display

Fig. 1 shows three alternative displays of the x-ray intensity pattern of the scanned image via a storage type oscilloscope display unit. Fig. 1(a) is a sort of three-dimensional plotting of the x-ray intensity pattern. The two axes on the bottom plane correspond to the x- and y- axes in the exposure field and the vertical axis represents radiopacity at each spatial sample point. The object in this figure is the head of the subject (lateral view of the tongue) uttering a vowel /i/. The sharp local peaks represent the metal pellets attached to the tongue and the upper and lower teeth. A gap between the upper and lower teeth is observed as a 'valley' running in the x-direction. For this scanned image, the number of the picture elements was 50 x 60, the distance between each sample point was 1 mm both in the x- and y- directions and the exposure time per sample point was 100 microseconds. The intensity values were spatially smoothed for this display. In Fig. 1(b), the same intensity data were displayed by plotting the equal brightness contour curves. In this mode of display, horizontal and vertical cursor lines are displayed superposed on the x-ray image. The positions of the cursor lines are controlled by manual switches and the coordinate values of the cross point can be read into the computer. In, Fig. (c), x-ray intensity at each sample point is coded in terms of partially black cells.

Exposure for the x-ray image in Fig. 1 was estimated at approximately $50\mu R$. The x-ray image with this low exposure was sufficient for monitoring the locations of the pellets and the approximate gesture of the tongue.

For the x-ray image storage and display with a greater number of picture elements and continuous gray scale, a scan converter tube has been used. During x-ray beam scanning, an x-ray intensity signal from the detector was written directly on the storage tube target. When scanning was completed, the intensity pattern was read out and displayed on the TV monitor. The method is useful for acquiring the image without using a large computer memory. Also, the picture noise due to the low photon density can be reduced to the required level by the repeated x-ray beam scanning and the superposed writing on the storage tube target, thus effectively integrating the intensity signal. Fig. 2 shows an example of the images displayed on the TV monitor.

Tongue Pellet Tracking

The strategy for the automatic tracking of the pellets on the tongue for observations of speech articulations was as follows. At each time frame, exposures were given to the sample points on a horizontal line centered at the pellet position detected at the previous time frame, and the point of minimum intensity was detected to determine the x-coordinate of the current pellet position. Using this x-coordinate value, a similar vertical line sweep was given to determine the y-coordinate value. Then the program proceeded to the next time frame repeating the same procedures. For the simultaneous tracking of several pellets, the same strategy was applied successively to each pellet at one frame time.

Prior to the tracking experiment, a scanned image such as shown in Fig. 1 was taken for the selected tongue gesture and the positions of the pellets were determined by visual inspection of the image. At the start of the pellet tracking, the subject was asked to wait, keeping the same tongue gesture as above. The initial positions of the pellets were detected by scanning the selected small area around the predetermined position of each pellet. Then the program proceeded to automatic pellet tracking and the subject started the pronunciation.

Generally, for each single run of the tracking program, a few hundred milliseconds were required for the initial detection of the pellets and, for the following time interval of several seconds, coordinate values of the pellets were stored in the core memory.

For the pellets on the tongue surface, nine sample points were sampled in the horizontal and vertical sweep respectively, with a distance of 0.5 mm between each sample point. Intensity values were smoothed for three contiguous points and the minimum value was detected. Current position of the pellet was detected by the linear interpolation (minimum square error) from the pellet positions of the preceeding four time frames and the sweeps at the current time frame were given centering at this predicted pellet position.

For the pellet attached to the jaw, sweep range was narrowed to sample seven points and the prediction of the current position was omitted, in consideration of its slower movement compared to that of the tongue pellet. For the pellet attached to the upper lip, where the attenuation of the x-ray beam was smaller and the noise in the intensity signal was lower, spatial smoothing of the intensity value was omitted and five points were sampled for each line sweep.

For two reference pellets which were generally attached to the upper front tooth and the surface of the nose for monitoring the movement of the head, pellet positions were sampled at every other time frame.

With the present computer (PDP-9, DEC CO.), computation time of 50-70 seconds per sample point was required for the above programs, allotting 40-50 μseconds exposure time per sample point. With this exposure, accuracy of approximately ± 0.5 mm was obtained in measuring the position of the pellet. In the case of the simultaneous tracking of four tongue pellets one jaw pellet, and one lip pellet with two reference pellets, the resulting frame rate was 130 frames per second.

Fig. 4 shows examples of the placements of the pellets that have actually been tested. In the case of Fig. 4(a), five pellets were attached to the surface of the tongue to see the details of the tongue contour, with one more pellet attached to the lower front tooth to observe the movement of the jaw. In Fig. 4(b), a pellet was placed in the vallecula to observe the movement of the tongue root. In Fig. 4(c), the backmost of the four tongue pellets was attached to a place as far back as possible on the surface of the tongue. A pellet was attached to the upper lip in addition to the pellet on the jaw.

Fig. 5 shows the trajectories of the pellet movements during an utterance of the continuous vowel sequence /ieaou/ in Japanese, recorded for each pellet placement shown in Fig. 4. Clustered points represent more or less stationary articulations of the vowels. Fig. 6 shows an example of the pellet movements recorded for the consonantal articulations. Fig. 6(a) shows the trajectories and Fig. 6(b), the time curves of the x- and y-coordinate values of each pellet.

X-ray exposure in these experiments was estimated at approximately $120 mR \cdot cm^2$ per minute, expressed in terms of the (exposure rate) x (exposure area). As for the (local) density of radiation in the pertinent portion of the tissues, the estimation of the maximum dose density may be obtained considering the case where all the pellets happen to stop moving. Then, the x-ray exposures are distributed to approximately 100 sample points, the effective exposure area being about $1\ cm^2$. Resultant exposure at these sample points is about 120 mR per minute.

On-line Contour Tracing

A test program for the automatic identification of the outline of the bone or other organs has been written and some model experiments have been conducted. Using the present program, the points of the (local) maximum in the slope of the spatial variation of the x-ray intensity were automatically traced by giving x-ray exposures only to a narrow area along the object contour.

First, a line-scanning at a manually specified position was made and the point of maximum variation of intensity on that line was determined as the starting point for contour tracing. Next, centered at this point, short vertical and horizontal sweeps were given to sample the points of the cross shaped array. On each sweep line, the point of maximum value of the slope of the intensity variation was detected. Based on these two points, a point on the contour was determined. Then, the direction and distance of the next sample point from this contour point was selected on the basis of the values of the slopes of the two points, and the same strategy was repeated centering at this sample point.

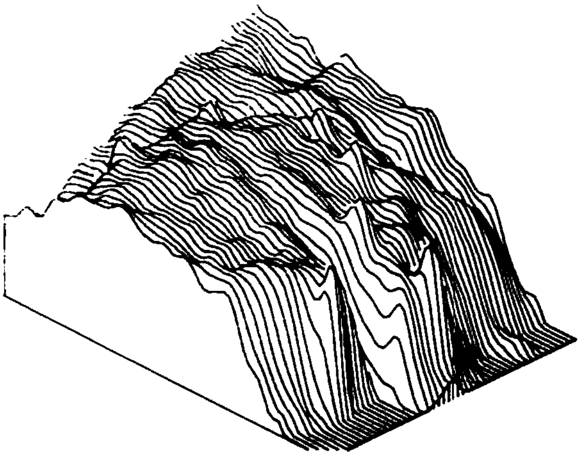
A test experiment was conducted by using a chicken leg as an object which was placed in a water layer of 8 cm in thickness. Fig. 7(a) shows the scanned image of the bones and Fig. 7(b), the equal brightness contour map around the bone joint. Fig. 7(c) shows the variations of the x-ray intensity along the horizontal scan lines depicted as A and B in Fig. 7(a), recorded for three different conditions of exposure time per sample point. With the shorter exposure time, the noise in the intensity signal increases and the process of automatic contour tracing becomes unstable. For this object, contour tracing was performed successfully with an exposure time of 1 millisecond per sample point. The outlines detected for three different exposure times in Fig. 7(c) are shown in Fig. 8. Two straight lines in each figure represent the initial scan lines specified for each bone.

A similar method has been applied to the automatic identification of the bone outlines around the hip joint area in a phantom of an infant. Bone models made of aluminium sheet 3 mm in thickness were used in this experiment. Fig. 9 (a) shows the initial scan lines and the directions of the contour tracing specified for each object bone. In this program, an algorithm was employed to stop contour tracing of a bone when it was detected that the running direction of the contour changed from the initial vertical direction to an approximately horizontal direction. Bone outlines detected for two different conditions of exposure are shown in Fig. 9(b). An exposure time of 0.5 millisecond per sample point was sufficient for the automatic tracing of the outlines in this experiment.

Acknowledgments

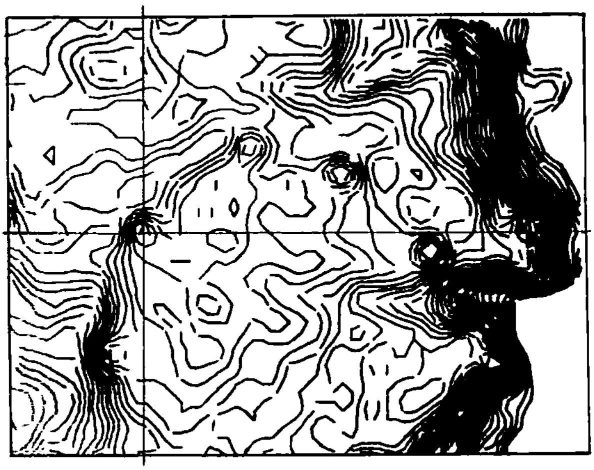
We wish to acknowledge with great gratitude the valuable cooperation of Dr. O. Fujimura, of Bell Laboratories. We also appreciate the valuable advice of Prof. E. Takenaka of Radiological Center, the University of Tokyo Hospital. Thanks is also due to Prof. Y. Tateno of the University of Chiba Hospital for his kind suggestions on the application of our x-ray technique to the observation of the bones in the phantom of an infant.

(a)



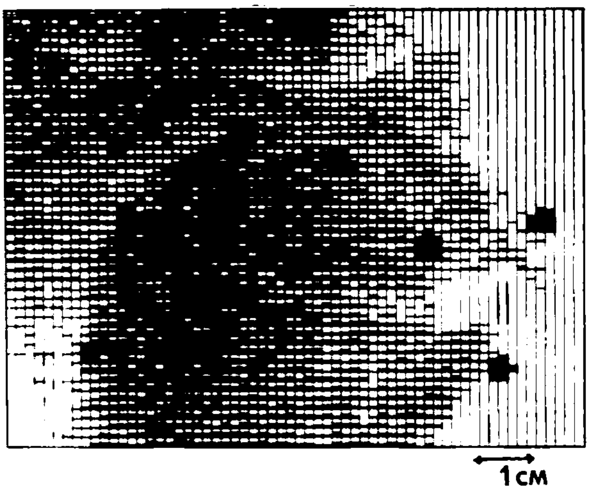
Three dimensional representation of the x-ray intensity pattern. Bottom plane: x- and y-coordinates in the exposure field. Vertical axis: radiopacity.

(b)



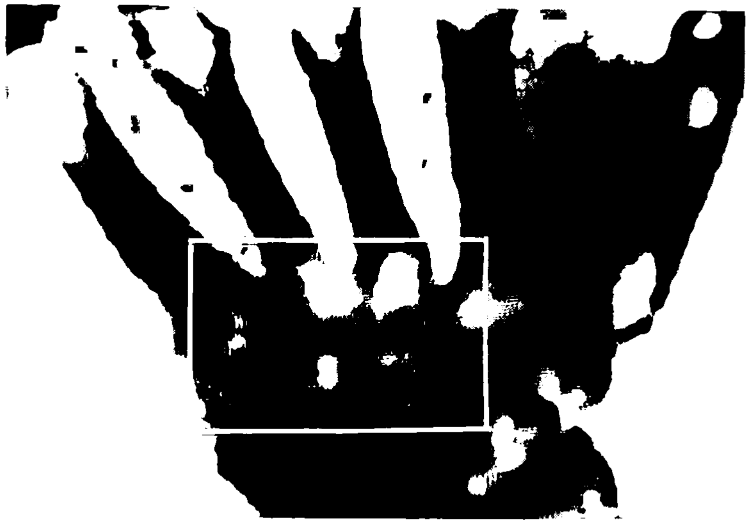
Equal brightness contour map.

(c)



Gray scale (quantized) representation.

Fig. 1: Displays of the scanned image via a storage type oscilloscope (lateral view of the tongue during the sustained phonation of vowel /i/ with several pellets placed on the tongue and teeth).



(a)

(b)

Fig. 2: Scanned image of a phantom of a hand obtained by use of a scan converter tube. A magnified image of the selected area in (a) is shown in (b).

(a) (b)

Fig. 3: A method for the automatic tracking of the moving pellet.

(a) Cross shaped array of the exposure points for detecting the pellet position.

(b) Exposures are given only to a narrow area along the trajectory of the pellet.

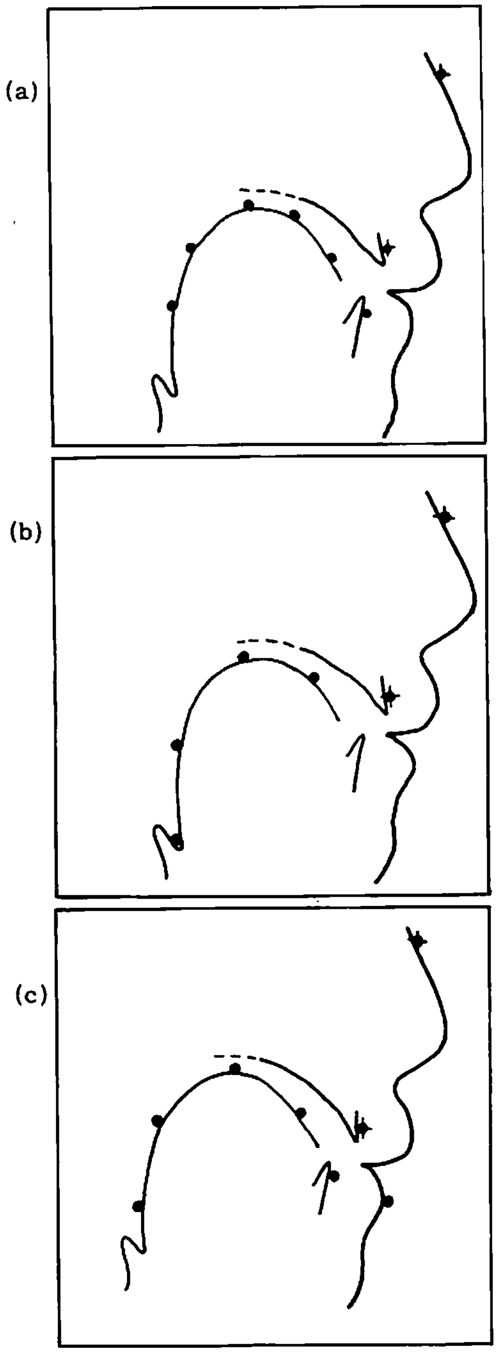


Fig. 4: Examples of the placement of the pellets for observing speech articulations. ✦: reference pellets for monitoring the movement of the head.

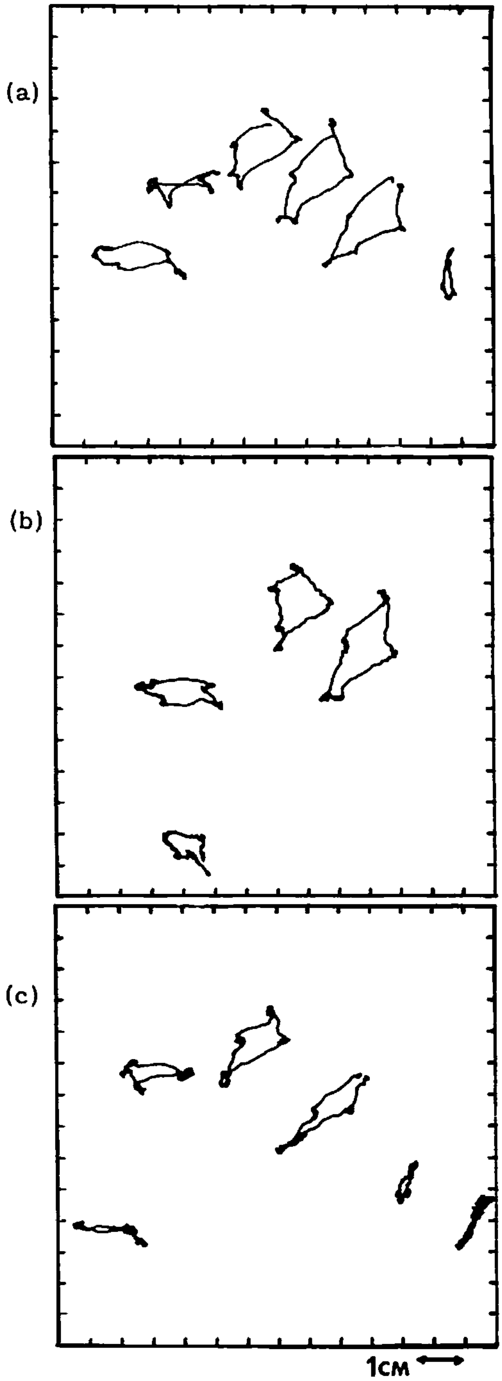
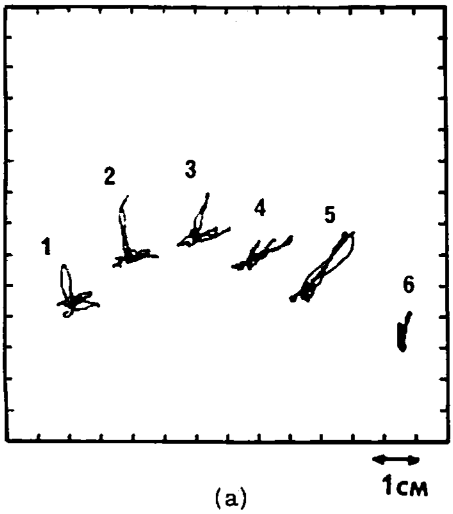
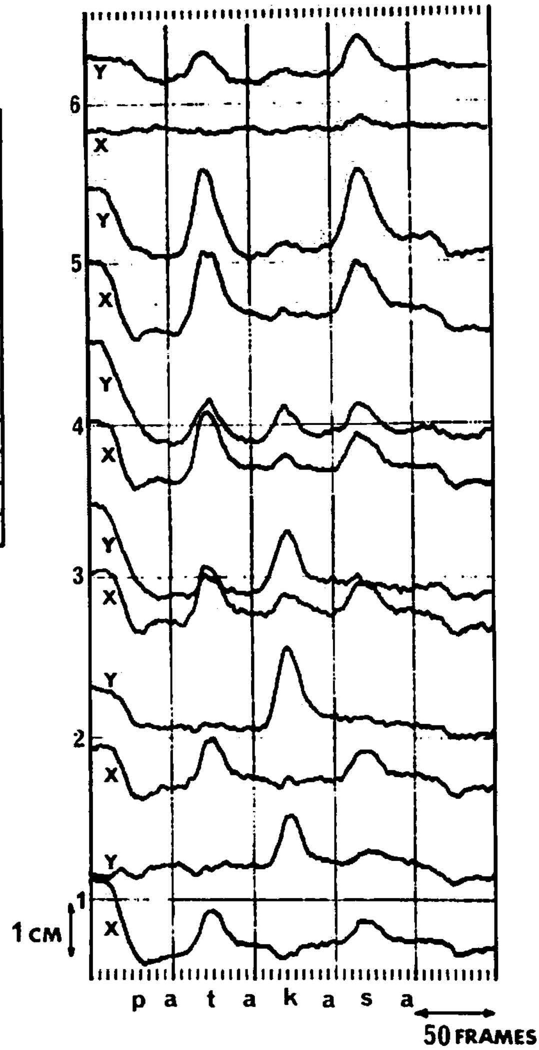


Fig. 5: Trajectories of the pellet movements during the utterance of the vowel sequence /ieaou/, recorded for three different placements of the pellets in Fig. 4.



(a)



(b)

Fig. 6: Trajectories (a) and time curves of the coordinate values (b) of the pellet movements for some consonant articulations (pellet placement, Fig. 4 (a)).

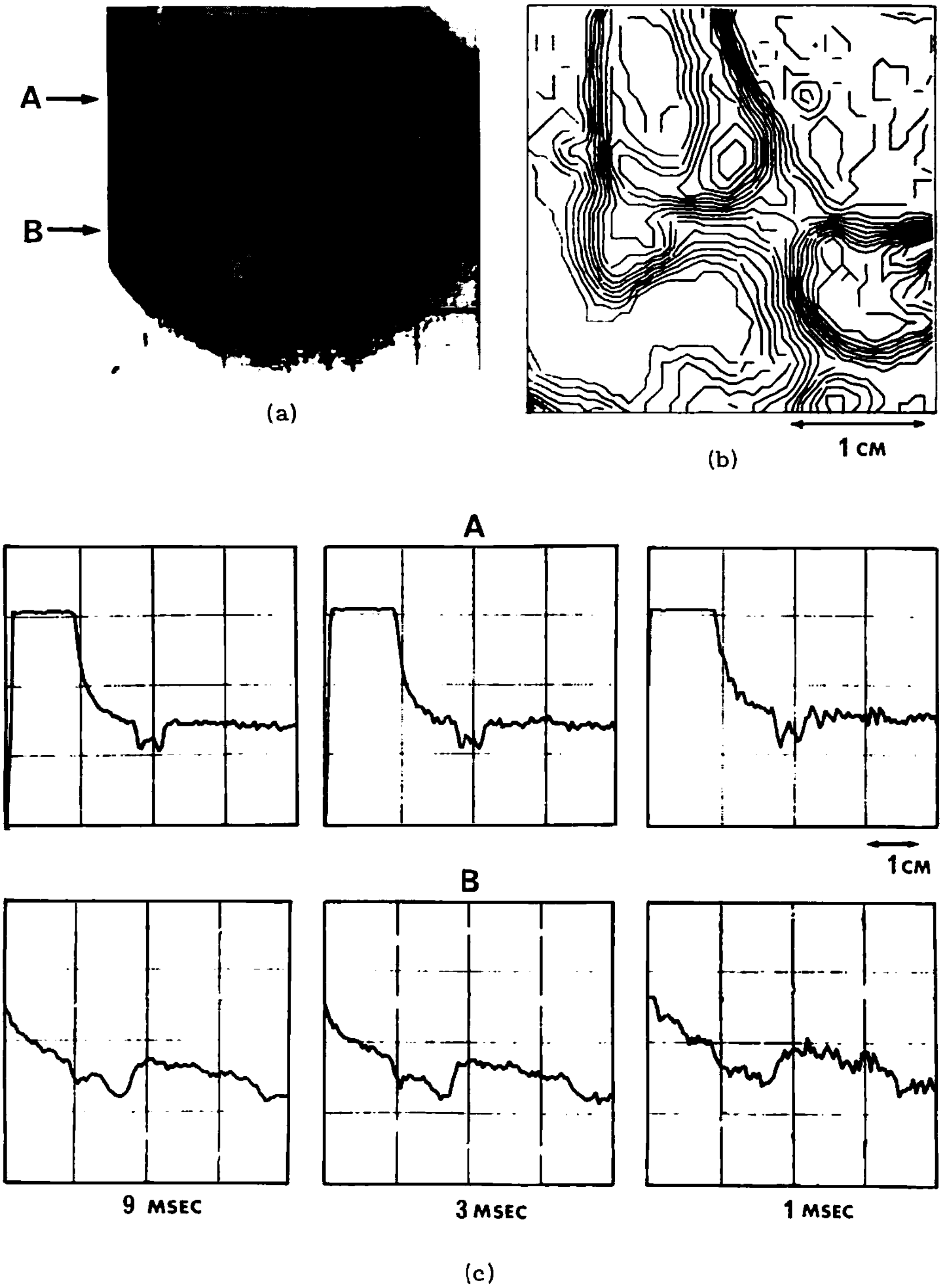
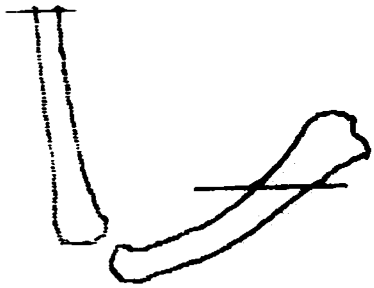
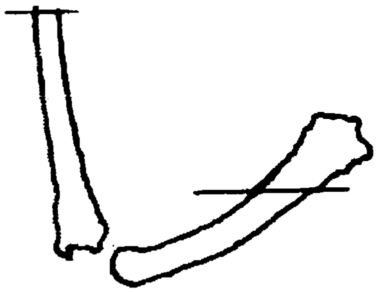


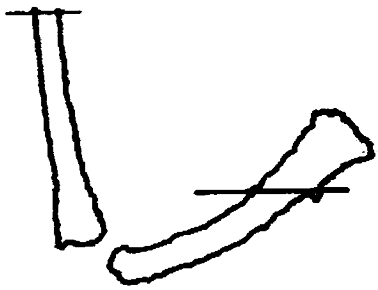
Fig. 7: (a) Scanned image of a chicken leg placed in a water layer.
(b) Equal brightness contour map of the intensity pattern around the joint.
(c) Variations of the x-ray intensity along the horizontal scan lines A and B depicted in (a) (three conditions of exposure time per sample point).



9 MSEC

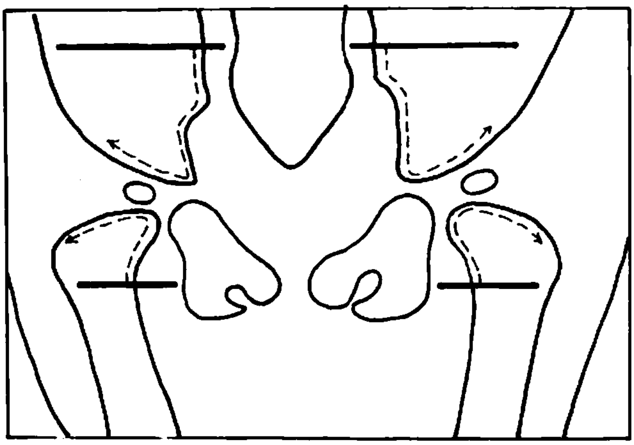


3 MSEC

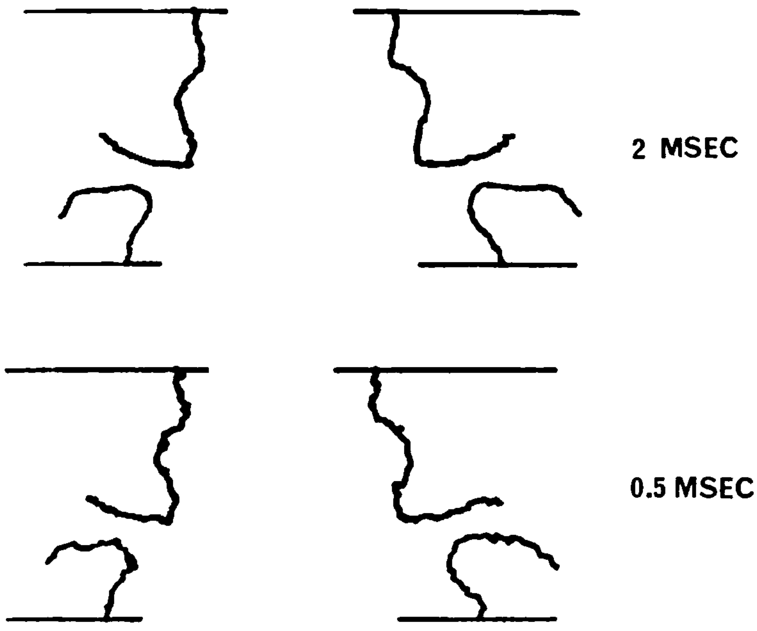


1 MSEC

Fig. 8: Bone outlines determined for three conditions of exposure time per sample point. Straight horizontal lines are the scan lines for initial detection of the bones.



(a)



(b)

Fig. 9: Identification of the bone outlines in the hip joint area of the model of an infant.
(a) Initial scan lines and the directions of the contour tracing for each object bone.
(b) Bone outlines determined for two different conditions of exposure time per sample point.

References

1) Kiritani, S., K. Itoh and H. Imagawa; (1974); "A High Voltage Thin X-ray Beam Scanner for Computer Controlled Radiography" Ann. Bull. RILP No. 8, 1-6.

2) Fujimura, O. (1967); "Medical Implications of On-line Computer Experiments in Speech Research" Tokyo J. Med. Sc. 75, 235-239.

3) Fujimura, O., S. Kiritani and H. Ishida (1973); "Computer Controlled Radiography for Observation of Movements of Articulatory and Other Human Organs" Computers in Medicine and Biology, 3, 371-384.