BIOSTEREOMETRIC METHODS FOR THE STUDY OF BODY SURFACE MOTIONS DURING BREATHING

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ABSTRACT

Methods are described for computing the motion vectors of discrete points on the body surface during breathing and for presenting them in a readily intelligible form. Discrete points of interest are targeted on the body surface. Stereophotographic pairs are taken from the front of subjects reclining in a reference frame. Co-ordinates of image points are measured with a stereocomparator. The shape of the surface is computed by interpolation. Total surface motions during breathing are derived from the differences between the breath-in and breath-out shapes. These results are shown as computer generated contour, profile or tridimensional plots. Spatial vectors are computed for each point from their co-ordinates at the extremes of the breathing cycle. The vectors are presented numerically or as scaled arrows superimposed on stereo-photographs of the body surface which, by closely relating displacement to structure, facilitates the physiologic interpretation of the data. We have characterised chest wall size, shape, and motion in children as small as 2,5 kg by these means. The method of presenting results as stereoscopic space vectors has merit in medicine and may have possibilities in demonstrating deformation of structures in the engineering field where points of interest have been targetted.

INTRODUCTION

The actions of the muscles of respiration are incompletely understood. "We know much about the lung but little about the muscles which pump it" (Macklem 1981). Insight into the function of the principal muscles of respiration - the intercostals and the diaphragm - can be gained by analysis of the motions of the body surface during breathing (Konno and Mead 1967). Conventional methods have however largely restricted studies to healthy adult volunteers, whereas it is necessary to study patients with paralysis of individual respiratory muscles in order to resolve controversies regarding their function.

Biostereometrics offers an elegant solution to this problem. The shape, linear dimensions, cross sectional area and volume change of the trunk during breathing have previously been determined by a photogrammetric method (optical contouring) in which tridimensional co-ordinates on the body surface are determined from distortions of coded patterns of light that have been projected onto it (Kovāts 1974, Peacock et al 1984, Gourlay et al 1984). Optical contouring however does not lend itself readily to physiologic studies that require the motions of specific regions of interest on the surface to be characterised and related to their associated structures. We present an alternative method.

METHODS

1. Photogrammetric and Computing Equipment

The system developed to undertake the non-invasive study of the movement of the surface of the chest and abdomen during breathing made use of the following photographic, photogrammetric and computing equipment:

a. Photographic: Two Pentax ME Super (f1,7 50 mm) 35 mm cameras fitted with electric winders (ME II, 2 frames per sec). One Metz Mecablitz 32CT2 electronic flash.

b. Photogrammetric: Zeiss Jena Steko 1818 stereocomparator on-line to a Hewlett Packard (HP) 9816 micro-computer.

c. Computing: HP 9816 series 200 micro-computer, HP 9121 disc drive, HP 7475A graphics plotter, HP 225A think-jet printer and Summagraphics ID-2-11/48 digitiser. The HP system was on-line to a Sperry 11/81 main frame computer.

d. Software: Through the Sperry main frame, use was made of a Saclant graphics package able to generate contour plots and 'tridimensional' perspective figures. Software for the HP system was produced in-house.

2. Reference Frame

Since non-metric cameras were to be utilized, in-situ calibration was necessary and two control frameworks were designed. One was constructed for babies and children up to 2 years of age (Figure 1) and another for children and adults. The frameworks comprised a perspex grid on which was mounted a hinged upper frame that included control targets consisting of small brass discs onto which black and white concentric circles were embossed. The larger framework consisted of an upper control field made up of taut intersecting piano wire in the form of a grid. The framework targets were coordinated in three dimensions by a combination of trilateration, levelling and optical plummet observations to relate the upper plane co-ordinates to the lower.

Figure 1

Attached to the control frameworks were rigid supports allowing for the mounting of two motor driven 35 mm cameras located approximately 1 m above the lower perspex grid and aligned with slightly converging lines of sight and a camera base distance of 0,4 m. The hinged upper portion allowed for the placing of subjects within the frame and the converging lines of sight of the cameras permitted the maximum image usage of the film format.

3. Photography

The surface of the torso is virtually featureless, therefore multiple small self-adhesive white paper targets annotated with ink crosses to serve as easily definable discrete point marks were affixed to it. The electric winders were activated by a common switch. Synchronous exposure was achieved by using slow shutter speeds (1/30 second), small apertures (f16) and a single electronic flash mounted mid-way between the cameras. A liquid crystal (LCD) numeric display linked to the shutter mechanism was placed adjacent to the patient, identifying the photographic pairs (Figure 6).

Photographs taken at breath-in and breath-out epochs were selected using recordings of the respiratory waveform on which the instant of each photograph was marked. The output of a respiratory monitor (HP 78202B), that operated with 3 disposable electrocardiograph skin surface electrodes, was recorded on a polygraph (HP 7758B), the event marker of which was coupled to the electronic flash.

4. Observational and Mathematical Procedures

Although the torso points of interest were targetted, thus permitting monoscopic observations, the original negative pairs (Ilford FP4, 125 ASA) were observed in stereoscopic mode in the Steko 1818 stereo comparator because this facilitated proper identification of the large number of common targets. Since the torso movement was small between the breath-in and breath-out epochs, the plane XY comparator co-ordinates recorded and displayed for the first epoch allowed for the proper matching of the same targets for the second epoch. The b_{ij} projective transformation parameters of the individual cameras were calculated by relating the single picture plate co-ordinates of the imaged tridimensional control framework points with their spatial coordinate values and using a modified 11 parameter mathematical solution approach (Adams 1981a and 1981b). A comparison of residual errors resulting from the use of redundant control points indicated that standard vector errors in the calculation of spatial values of the discrete targetted points would seldom exceed 0,5 mm, which further demonstrates that in-situ calibration produces highly satisfactory results even when using simple non-metric cameras.

5. Motion Vector Representation

The study was directed towards quantifying the spatial movement of the torso between breath-in and breath-out epochs. The absolute XYZ values of the discrete points were of less interest than the space vector displacements between the two extreme positions of each target as respiration took place.

An apparently novel method of presenting the movements in the form of exaggerated but scaled space vectors superimposed photographically on a 'breath-out' stereoscopic pair of photographs has been developed (Figure 5). The procedure adopted to produce the space vectors combines computational, graphical and photographic exercises.

During the in-situ calibration of the individual cameras the b_{ij} transformation parameters of each camera are derived (Adams 1981a, 1981b). Since the XYZ co-ordinates of the discrete points at the breath-in epoch are known it is a simple matter to compute the two dimensional comparator co-ordinates of these points as they would have theoretically imaged on the left and right hand pair of breath-out epoch pictures respectively. The movement of the torso would then be imaged on the left and right hand pictures as two dimensional vectors superimposed on the appropriate target points. Viewed stereoscopically the breath-out stereo pair would now include spatially oriented and enlarged but true to scale artificial 'arrows' representing the movements. A good estimate of the magnitude of the individual movements is possible since the scale of the vector arrows is known. The graphical procedure adopted to produce the space vectors consisted of plotting the arrows at an exaggerated scale onto a transparent medium using the HP graphics plotter. The vector magnitude enlargment was necessary since torso movement can be less than 5 mm. The appropriate transparent overlays were then placed on the emulsion side of an unexposed orthochromatic photographic print paper and under an enlarger carrying the breath-out negative. By trial and error the scale of print enlargement and the position of the overlay were adjusted until the origins of the space vectors appeared to coincide with the appropriate targetted points on the torso. The sensitised paper was then exposed to white light to produce one of the pictures making up the stereoscopic pair. Numerical presentation of vector results enables the mean vector for any given area of interest to be calculated.

PRESENTATION OF RESULTS

This project attempted to quantify the movement of the surface of the chest and abdomen in children, aged between 1 week and 4 years and with a body mass as low as 2,5 kg, by comparing the spatial position of discrete points at the extremes of the breath-in and breath-out epochs. Stereophotogrammetry can provide that information to high precision in the form of tridimensional XYZ co-ordinates. The presentation of this spatial information in an easily comprehensible form creates problems however. Providing a string of tridimensional digits, however precise, tends to become a meaningless exercise in the interpretive process. A contour plot of epoch differences gives an overall graphical representation in the form of a map but may be difficult to interpret (Figure 2). A computer generated tridimensional perspective view derived in conjunction with a differences contour plot gives a useful visual representation but lacks metrical information (Figure 3). Scaled two dimensional plan and height vector displacement 'arrows' superimposed on a computer generated outline of the patient are easily understood and provide the metrical and directional information desired but they nevertheless lack the realism of 3 dimensional space (Figures 4 and 8). Viewing the pair of stereo photographs on which motion vectors are represented in the form of exaggerated but scaled arrows gives a dramatic spatial illustration of the movement of the torso (Figure 5). When epoch differences are large, they can be readily appreciated by inspection of conventional contour plots. This is illustrated by a case of funnel chest deformity (pectus excavatum) who had marked indrawing of the lower sternum during inspiration (Figures 6, 7, 8, 9 and 10).

The fact that the body surface is viewed only from the front restricts the degree to which the shape can be characterised but does not seriously limit motion and volume determinations. Morgan and colleagues (1984) have shown that approximately 96% of chest motion is detected from a single point of view in front of recumbent patients. The need to make observations manually with a stereo comparator is a problem that currently constrains application of the method and for which real-time photogrammatry offers a potential solution.

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PLOTS OF EPOCH DIFFERENCES

Breath-In minus Breath-Out

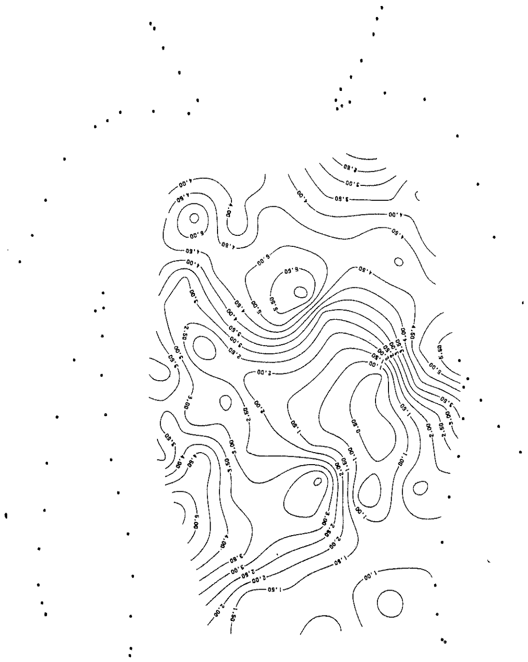

Figure 2

CONTOUR PLOTS: Interval 0,5 mm

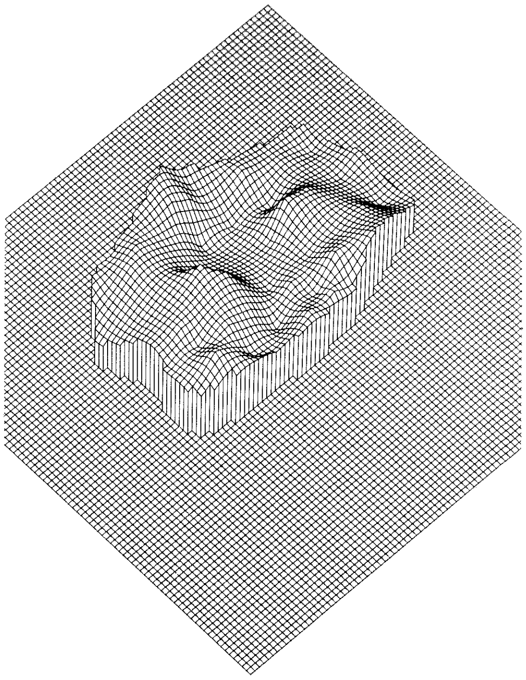

Figure 3

3-D VIEW. Grid Interval 5 mm.
Z exaggerated x10

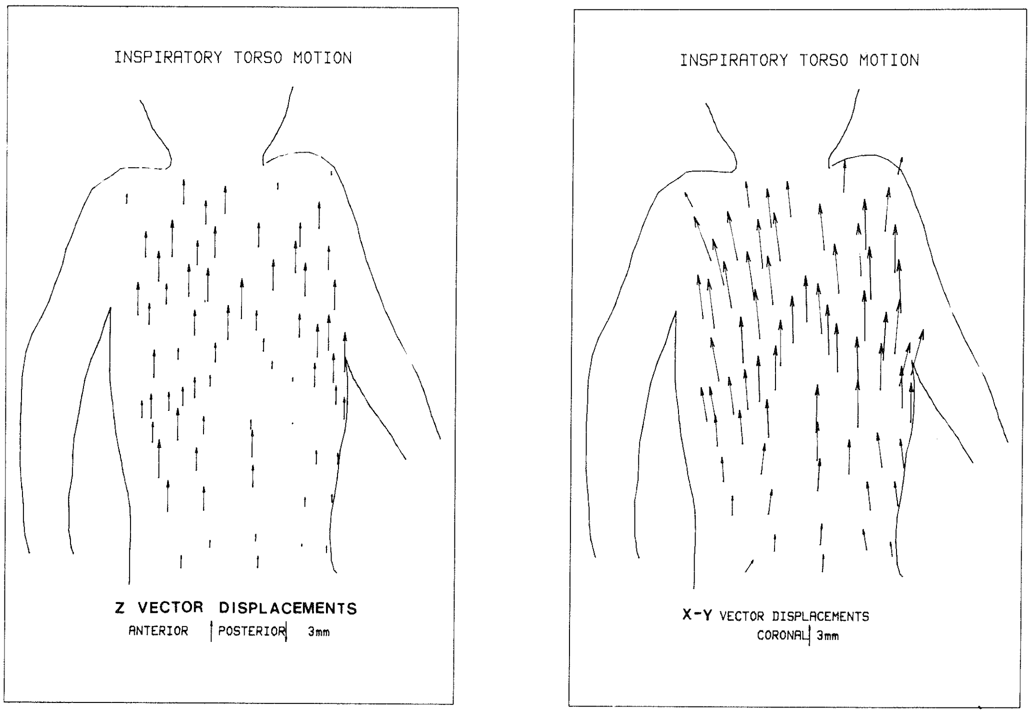

Figure 4 : VECTORGRAPHS

STEREOSCOPIC SPACE VECTOR REPRESENTATION

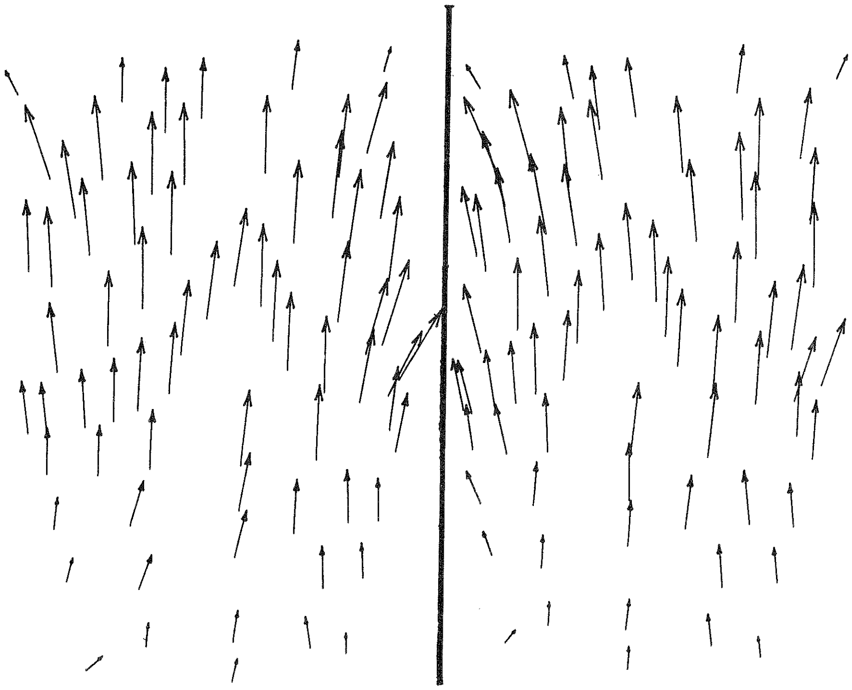

Figure 5A

STEROGRAM OF COMPUTED SPACE VECTORS AS PLOTTED ON TRANSPARENT OVERLAY

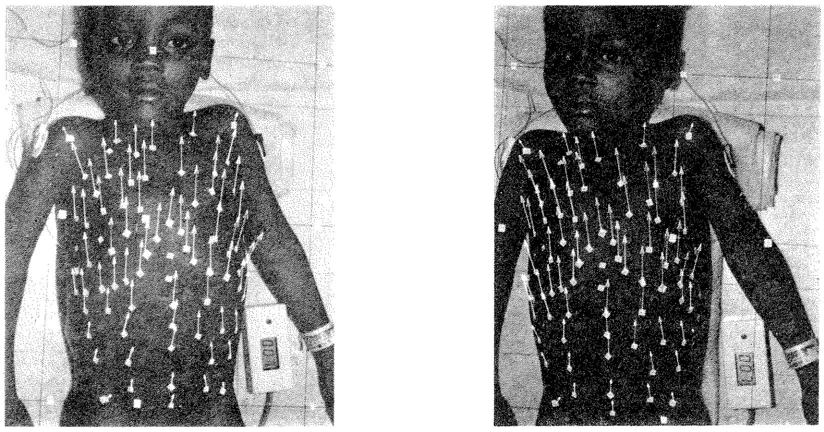

Figure 5B

SPACE VECTORS (Figure 5A) SUPERIMPOSED PHOTOGRAPHICALLY ON BREATH-OUT STEREOSCOPIC PAIR

PICTORIAL DEMONSTRATION

Funnel Chest Deformity in a 2 Year Old Boy.

The depression in the centre of his chest is greatly exaggerated when he breathes in.

Figure 6

STEREOGRAM : BREATH-IN EPOCH

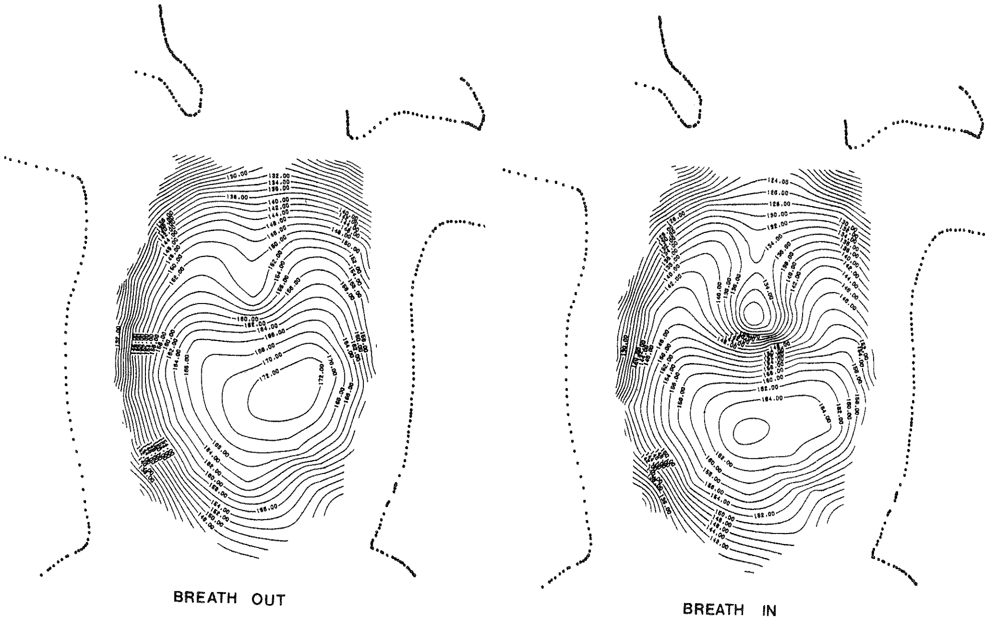

Figure 7

ABSOLUTE PLOTS : CONTOUR INTERVAL 2 mm

PLOTS OF EPOCH DIFFERENCES

Breath-In minus Breath-Out

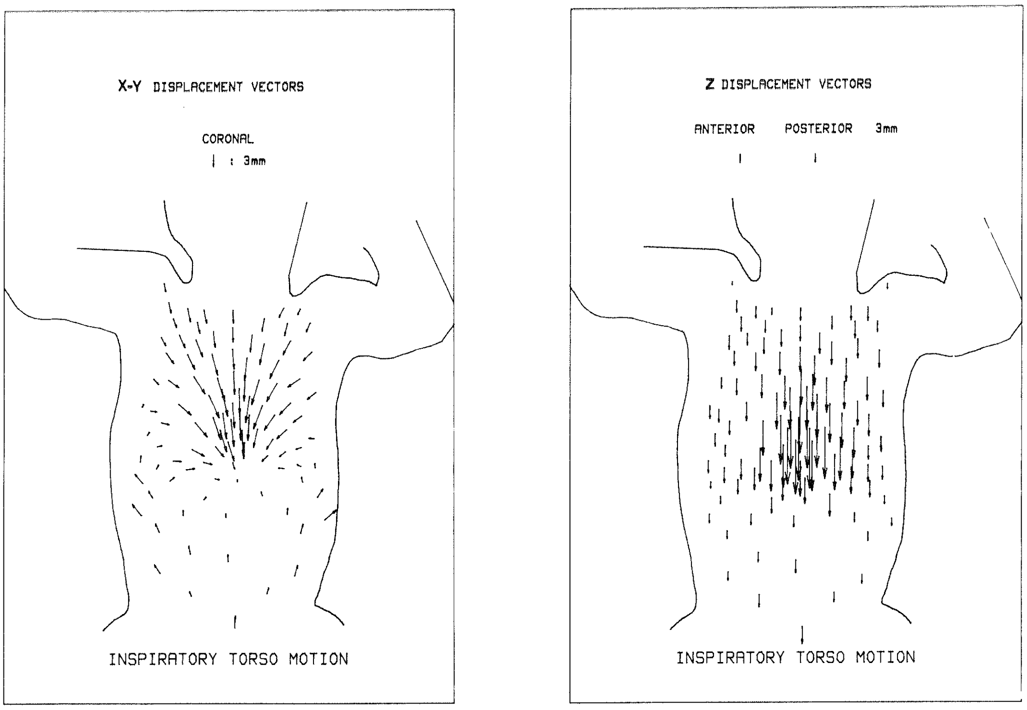

Figure 8 : VECTORGRAPHS

Figure 9

CONTOUR PLOT INTERVAL 1 mm

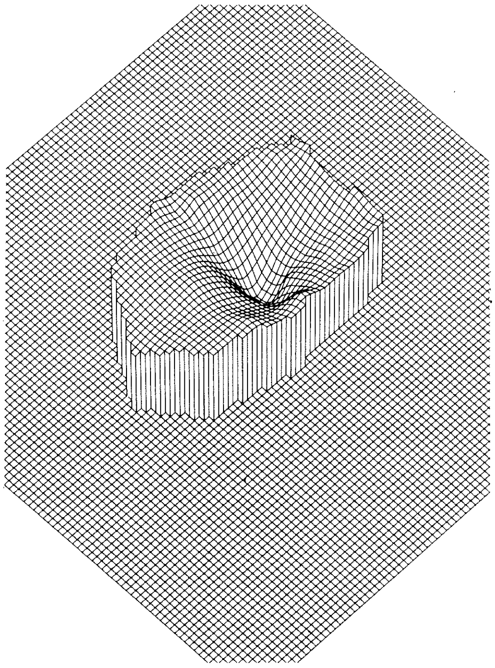

Figure 10 : 3-D VIEW

Grid Interval 5,5 mm. Z exaggerated x5