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. Stereo-
photographic 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 targeted.

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 (Kováts
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 s;c). One Metz Mecablitz 32CT2
electronic flash.

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

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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 mainframe computer.

d. **Software:** Through the Sperry mainframe, 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.

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 11
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
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 11 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 enlargement 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 photogrammetry offers a potential solution.

ACKNOWLEDGEMENTS

Ann Tregidga did most of the measurements and carried out the necessary computations. Heinz Rüther and Peter Adams wrote most of the software for the Hewlett Packard and Douglas Kirby constructed the control frames. Their assistance is gratefully acknowledged, as are funds provided by the Council for Scientific and Industrial Research (CSIR) Foundation for Research Development, the S.A. Medical Research Council, the University of Cape Town Staff Research Fund and Heran and Caporn Bequest, and the Institute of Child Health Fund. The Faculty of Medicine's Ethics and Research Committee approved the project.

REFERENCES


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