Neuroendocrinology Letters Nos.1/2, Feb-Apr Vol.25, 2004
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ORIGINAL ARTICLE

Pregnant Women: Moiré Contourgraph and it's Semiautomatic and Automatic Evaluation

DEDICATED TO PROFESSOR ANTONÍN DOLEZAL ON HIS 75TH BIRTHDAY ANNIVERSARY

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Submitted: *January 15, 2004*
Accepted: *January 29, 2004*

Key words: **Moiré contourgraph; pregnant women; computer evaluation**

Neuroendocrinol Lett 2004; ***25****(1/2):52–56 NEL251204A04 Copyright © Neuroendocrinology Letters* ***www.nel.edu***

Abstract

THE AIM OF THE STUDY: Methods of automatic and semiautomatic picture determination, evaluation of Moiré contourgraph applied to pregnant women
TYPE OF THE STUDY: Development of algorithm, experimental biomechanical study of the dynamics of pregnant women's axial system.
METHOD: Achieving the correct data for 3D picture analysis derived from 2D pictures requires further precision making. In general, it requires algorithmization and elaboration of software plug-in, which make processing of enormous number of picture data significantly faster. The following corrections, adjustments and calculations had to be done to be used for Moiré contourgraph:

- correction of the radial distortion of the lens – *automatically*,
- aligning the histogram – *automatically,*
- picture detection of the defined object shape and determining its centre of gravity with sub-pixel precision – *automatically,*
- centre of gravity of the picture of the cross-section of pseudo-contour line of the Moiré contourgraph – *semi-automatically*,
- correction of radial shifts in 2D – data orthonormalization – *semi-automatically,*
- determining the distance of a projected point in 2D from the net as z-coordinate in 3D – *semi-automatically,*

a) points projected in 2D picture on the pseudo-contour line,
b) points not projected in 2D picture on the pseudo-contour line.

RESULTS: Algorithmization of each approach leading to semi-automatic and automatic processing of data obtained from Moiré contourgraphs. Main distortions, errors and inaccuracy of picture data are eliminated. The resulting position of the detected point in 3D derived from the 2D picture is determined with sub-pixel precision of primary picture coordinates.
CONCLUSION: Precision given to coordinates of reference points obtained from original picture data allows for eliminating limiting inaccuracy in determining real coordinates of a 3D object from 2D Moiré contourgraph. Coordinates of a virtual model of a real object corresponding to its real values are determined. This makes the base for non-invasive recording and reconstruction of data on the human body's shape including the details in 3D. The presented file of methods will be used to assess dynamics of the women's axial system during their pregnancy and one year after giving birth.

Introduction

The research to "Shape and Reological Reactions of Gravid Women to Mechanical Load" is based on methods of shape detection through its picture. The Moiré contourgraph method allows for non-invasive recording of the human body shape characteristics [1] Identification of changes in the shape as a reaction to mechanical and biological load is carried out in form of a reconstruction of 3D through 2D picture with implicit space information on the detected point's position. Semi-automatic and automatic data processing developed by means of mathematical methods, aimed at shape and position identification of the projected data with necessary correction of the projection distortion and errors, is of a great importance.

Figure 1 shows a basic picture of a pregnant woman taken by Moiré technology, which, after all necessary corrections have been done, provides space characteristics of e.g. position of selected segments of the axial system, shape of the gravid abdomen, etc.

Problem

Precision of projected data

The following corrections, adjustments and calculations had to be done to be used for Moiré contourgraph:

- correction of the radial distortion of the lens – *automatically*,
- aligning the histogram – *automatically,*
- picture detection of the defined object shape and determining its centre of gravity with sub-pixel precision – *automatically,*
- centre of gravity of the picture of the cross-section of pseudo-contour line of the Moiré contourgraph – *semi-automatically*,
- correction of radial shifts in 2D – data orthonormalization – *semi-automatically,*
- determining the distance of a projected point in 2D from the net as z-coordinate in 3D – *semi-automatically,*
  a) points projected in 2D picture on the pseudo-contour line,
  b) points not projected in 2D picture on the pseudo-contour line.

Methods

Correction of the radial distortionof the lens

In a measuring lens, correction of the radial distortion of the lens is provided so that the function correcting this fault corrects the distortion values in the direction from the centre to the side, to the chosen mean value around zero. Its course is shown in figure 2A. Figure 2B shows the distortion values projected through

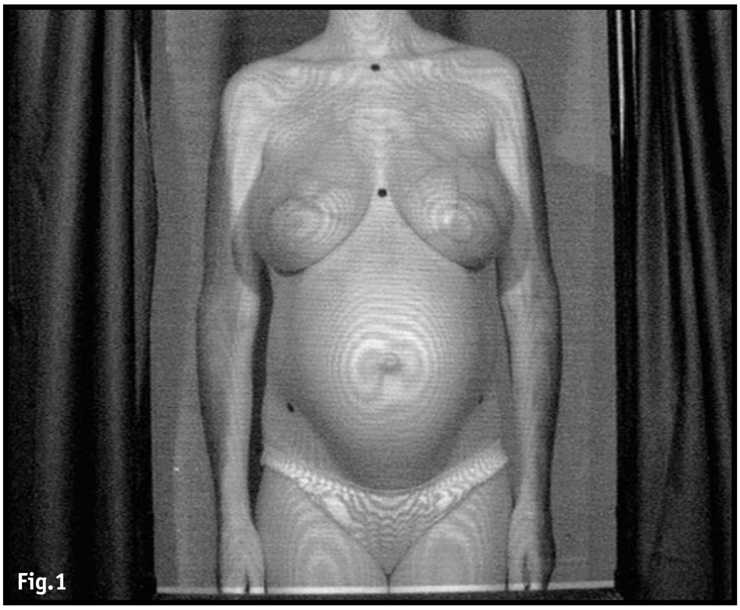
Fig.1

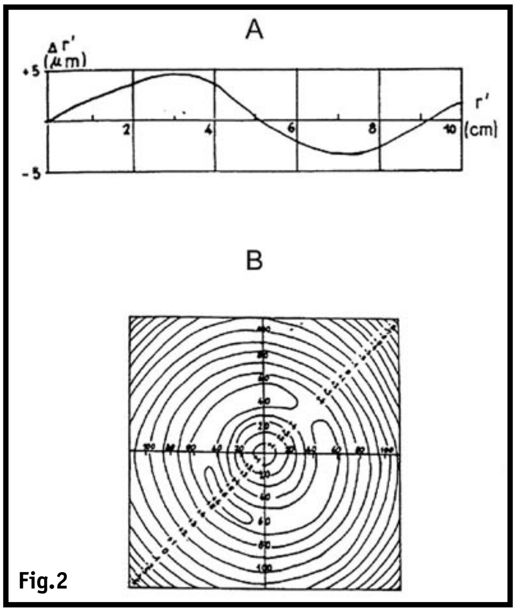

Fig.2

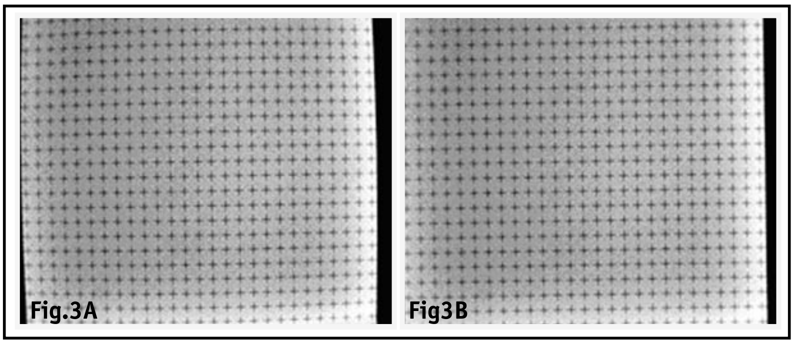
Fig.3A
Fig3B

Fig.1 Standard picture of Moiré contourgraph with points marked on the gravid woman's body

Fig. 2 Distortion of a measuring lens.
A – corrected to the mean value around zero
B – distortion values projected through isolinen

Fig. 3 Correction of the radial distortion of the lens
A – original picture - distortion
B – distortion eliminated (not rotation).

isolinen in the whole projection field of the lens. In a non-measuring lens, the distortion is usually an increasing function towards the side of the projection field [2]. .

Correction of radial distortion for the lens we use special program ExDistorzer. Finding the appropriate coefficients for reparative equations is held through the iteration method. The algorithm is specially designed for a close soft-copy photograph, allowing for calculation for narrow bundles of projection beams.

The total sum of the projection errors of the lens can be identified through observation, see Fig. 3. The differences in positions of the centre of the crosses in the direction from the picture centre towards its side is up to 13 pixels, which is a half of the distance between the centres of the crosses (26 pixels). The real distance between the centres of the crosses slightly exceeds 28 mm. This implies that the projection error on the side of the projection field is minimum 14 mm. Except for that, the radial shift error must be also considered [3,4].

Aligning histogram

Histogram aligning is a necessary correction of luminosity function f(x,y) of the picture. Value of luminosity function of the chosen surroundings of every pixel adjusts to a counted medium value of luminosity function of the whole picture. It's being done to unify (align) luminosity pixel values, so that it would be possible to perform better for instance thresholding when detecting concrete object shape – for instance picture mark on human body see Fig.4B.

Picture detection of the defined object shape and defining its centre of gravity with sub-pixel exactness

In Fig. 4D there is an example of determining statutely specified coordinate of automatically found centre of gravity of circle mark's picture to the tenth of pixel.

Looking for marks in the picture runs as marking the object which fulfills several conditions. Its average in pixels must be withing given limits, must be darker than the given threshold and must fulfill the condition of circular shape that is being tested with the help of rotating momentum invariants. Moments of the researched object are being counted first for statute $p+q$ from 0 to 3:

$$m_{pg} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x^{p} y^{a} f(x,y)\, dxdy \,, \quad (1)$$

where luminosity function *f(x,y)* has inside the object its own luminosity value and outside the object it is zero. In case that luminosity is zero everywhere inside, the value 1 is being considered inside and 0 outside. Centre of gravity may be counted from the moments:

$$x_t = m_{10} / m_{00} \,,\; y_t = m_{01} / m_{00} \,. \quad (2)$$

If the object is evaluated as a mark the coordinates of the centre of gravity are recorded in the database. General moments are then recounted to the central ones:

$$\begin{aligned}
\mu_{20} &= m_{20} \quad m_{10}^{2} / m_{00} \\
\mu_{11} &= m_{11} \quad m_{10} m_{01} / m_{00} \\
\mu_{02} &= m_{02} \quad m_{01}^{2} / m_{00} \\
\mu_{30} &= m_{30} \quad 3m_{20} m_{10} / m_{00} + 2m_{10}^{3} / m_{00}^{2} \\
\mu_{21} &= m_{21} \quad 2m_{20} m_{01} / m_{00} \quad 2m_{11} m_{10} / m_{00} + 2m_{10}^{2} m_{01} / m_{00}^{2} \\
\mu_{12} &= m_{12} \quad 2m_{02} m_{10} / m_{00} \quad 2m_{11} m_{01} / m_{00} + 2m_{10} m_{01}^{2} / m_{00}^{2} \\
\mu_{03} &= m_{03} \quad 3m_{02} m_{01} / m_{00} + 2m_{01}^{3} / m_{00}^{2}
\end{aligned} \quad (3)$$

The result is the same as if the moments were directly counted in coordinate systém starting in the centre of gravity. Then 6 rotating momentum invariants are counted [5].

$$\begin{aligned}
I_1 &= (\mu_{20} + \mu_{02}) / \mu_{00}^{2} \\
I_2 &= ((\mu_{30} + \mu_{12}))^2 + (\mu_{21} + \mu_{03})^2) / \mu_{00}^{5} \\
I_3 &= ((\mu_{20} + \mu_{02})((\mu_{30} + \mu_{12})^2 + (\mu_{21} + \mu_{03})^2) + 4\mu_{11}(\mu_{30} + \mu_{12})(\mu_{21} + \mu_{03}))) / \mu_{00}^{7} \\
I_4 &= (\mu_{11}((\mu_{30} + \mu_{12})^2 + (\mu_{21} + \mu_{03})^2) - (\mu_{20} - \mu_{02})(\mu_{30} + \mu_{12})(\mu_{21} + \mu_{03})) / \mu_{00}^{7} \\
I_5 &= ((\mu_{30} - 3\mu_{12})(\mu_{30} + \mu_{12})((\mu_{30} + \mu_{12})^2 - 3(\mu_{21} + \mu_{03})^2) + (\mu_{03} - 3\mu_{21})(\mu_{21} + \mu_{03}) \\
&\quad ((\mu_{21} + \mu_{03})^2 \quad 3(\mu_{30} + \mu_{12})^2))) / \mu_{00}^{10} \\
I_6 &= ((\mu_{03} - 3\mu_{21})(\mu_{30} + \mu_{12})(3(\mu_{21} + \mu_{03})^2 - (\mu_{30} + \mu_{12})^2) + (\mu_{30} - 3\mu_{12})(\mu_{21} + \mu_{03}) \\
&\quad (3(\mu_{30} + \mu_{12})^2 - (\mu_{21} + \mu_{03})^2))) / \mu_{00}^{10}
\end{aligned} \quad (4)$$

The object is evaluated as approximately circular and thus the mark, if the values of invariants lie within the following limits:

I_1 between 10^{-4} a 10^{-3},	I_4 between –1 a 1,
I_2 between 0 a 10^5,	I_5 between -10^9 and 10^9,
I_3 between –1 a 1,	I_6 between -10^7 a 10^7,

Thus found marks are then recorded in the relevant table in the open database with already subpixel exactness.

The picture's centre of gravity of the pseudo-contour line's section of Moiré contour graph

On the basis of the counted subpixel exacting of 2D coordinates of picture data (see higher calculation of the center of gravity) it is then possible to determine expressively more precisely the point (mark) location in 3D.

It may be done for instance with the help of more precise coordinate of the centre of gravity of pseudo-contour line's axis section in the chosen

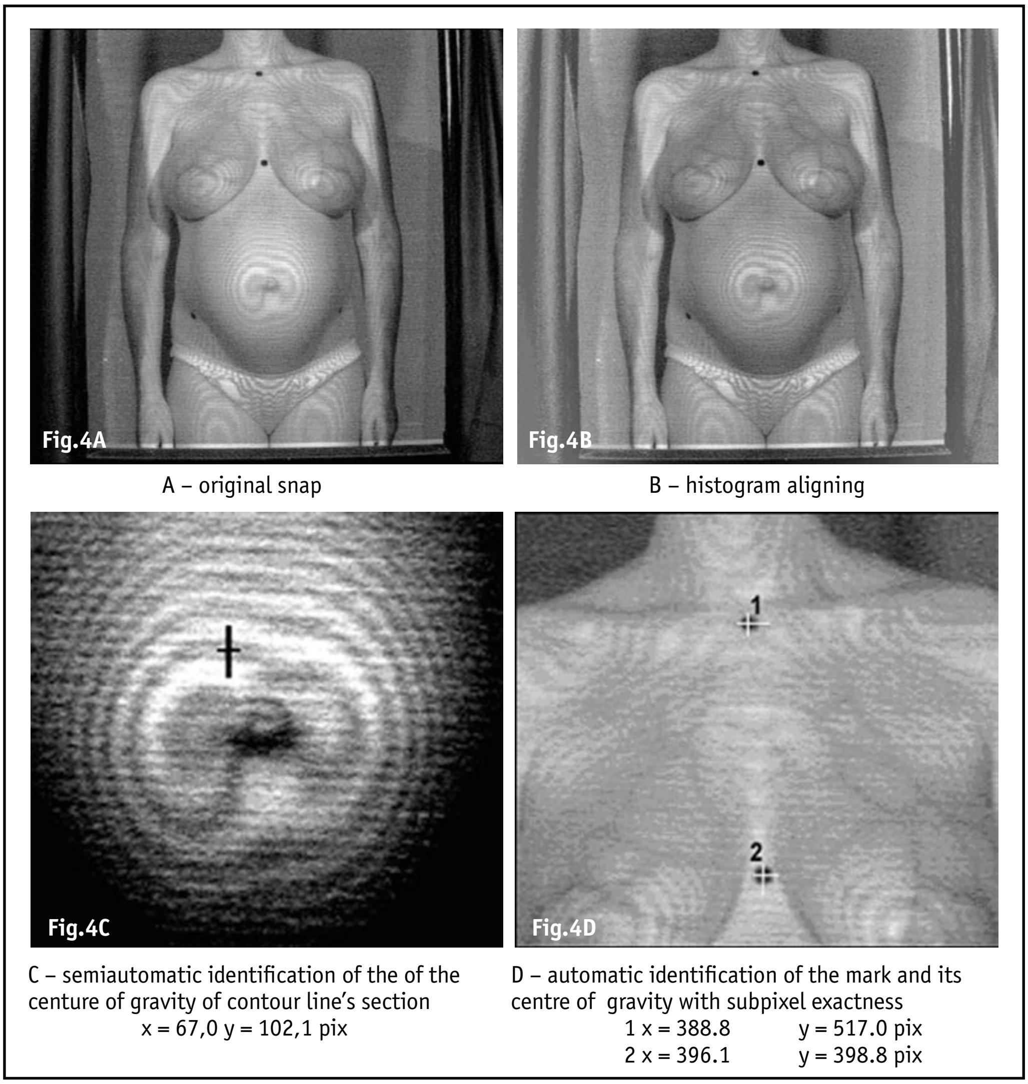

Fig. 4. Some snap corrections in semi-automatic and automatic identification of the shape (form) and calculation of its centre of gravity.

location. It's being searched for instance with the help of centre of gravity of abscissa composed of pixels of the chosen vertical section of contour line's picture in the required place. The value of z-coordinate of the searched point may be then found as functional value of approximating function for the exacted values of non-equidistant as well as equidistant indipendent variable.

Approximating function is being searched for discrete sequence of axes of the following pseudo-contour lines in the given direction and the corresponding z-coordinates with non-equidistant step of functional values see Table 1.

Correction of radial shifts in 2D – ortonormalization of data

There is a scheme of the origin of radial shift in central projection in Fig. 5. In the hemisphere **h** there is a real size of concrete coordinate of the chosen point on its surface. By the influence of central projection it only appears in **B** point, not ortonormally in point **A.** The difference B – A is a radial shift, which must be corrected for every coordinate of every shown point not lying in the axis of scanning.

$$X = x.\left(1 + \frac{\Delta.l_n}{l}\right).S$$

$$Y = y.\left(1 + \frac{\Delta.l_n}{l}\right).S \qquad (5)$$

This transformation equations may be derived from the given scheme or they may be found in [1].

Table 1. The values of camber between neighbouring pseudo-contour lines

ln	[mm]	dif. [mm]
1 =	4.85	–
2 =	9.72	4.87
3 =	14.62	4.90
4 =	19.55	4.93
5 =	24.51	4.96
6 =	29.49	4.98
7 =	34.50	5.01
8 =	39.55	5.04
9 =	44.62	5.07
10 =	49.71	5.10
11=	54.84	5.13
12=	60.00	5.16
13=	65.19	5.19
14=	70.40	5.22
15=	75.65	5.25

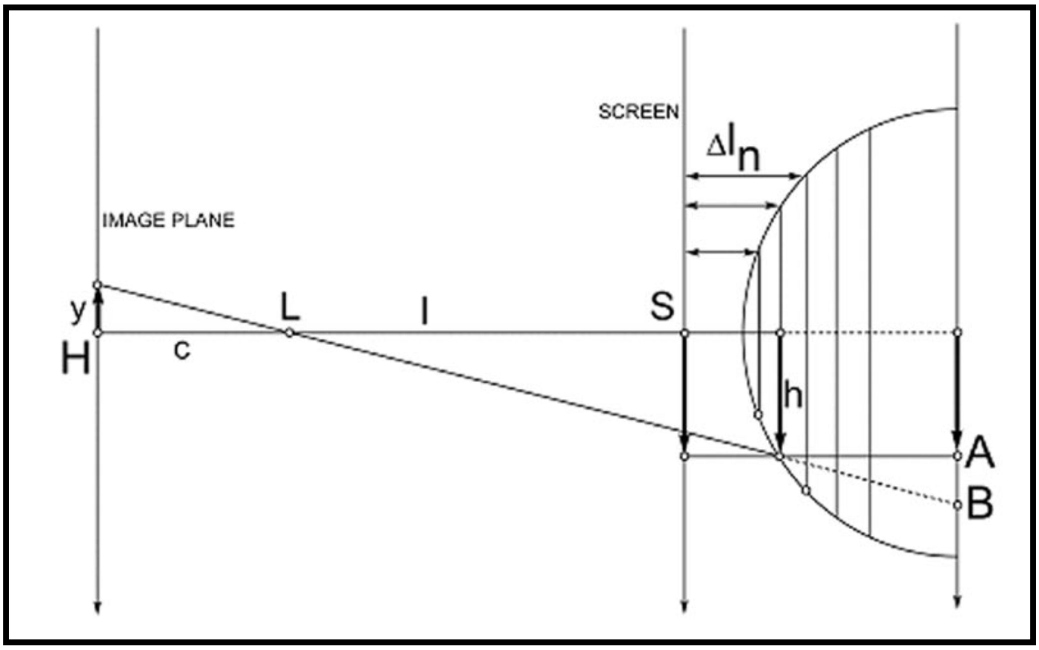

Fig. 5. The scheme of the origin of radial shift in central projection.

The distance of the shown point in 2D from the grid as z-coordinate in 3D

a) The points lying in 2D picture on pseudo-contour line

For individual contour-lines and space distances from the grid which they represent pay these relations:

$$l_n = (n * l) / (k - n)$$
$$N = l_{n+1} - l_n . \qquad (6)$$

b) The points not lying on pseudo-contour line in 2D picture

Linear approximation may be led for the point lying between two centres of gravity of neighbouring pseudo-contour lines.

But it's necessary in relation (5) to relative distance increase $\boldsymbol{l}$ to add approximated value to Δl_n for location of the searched point between both appropriate pseudo-contour lines. It means to approximate z-coordinate as total sum of the whole value for the preceding pseudo-contour line and approximated value.

Results

The study produces algorithmization of each approach leading to semi-automatic and automatic processing of data obtained from Moiré contourgraphs. Main distortions, errors and inaccuracy of picture data are eliminated. The resulting position of the detected point in 3D derived from the 2D picture is determined with sub-pixel precision of primary picture coordinates.

Discussion

Precision given to coordinates of reference points obtained from original picture data allows for eliminating limiting inaccuracy in determining real coordinates of a 3D object from 2D Moiré contourgraph. Coordinates of a virtual model of a real object corresponding to its real values are determined. This makes the base for non-invasive recording and reconstruction of data on the human body's shape including the details in 3D. The presented file of methods will be used to assess dynamics of the women's axial system during their pregnancy and one year after giving birth.

Acknowledgement

This project is being supported by research intention MSM 115100003.

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