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Deformation measurement of a human back using Moiré technique

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ABSTRACT

Simulated deformation of a human back is measured using Moiré technique (MT). The reproducible positions of human body are fixed by using two scales for measurement of the weight and by measuring the distance of the tip of left hand from the left knee. Shadow and projection Moiré are performed on the body for each position. The actual measurement of the deformation is performed by using projection Moiré approach. Fringe interpretation of the obtained Moiré figures is performed by using " Quick Fringe" software (QFS). The programs are modified according to the task of the experiment. Contour, 1-Dimensional and 2-Dimensional representations of the surface of the deformations is obtained for four selected positions of the human back. MT and fringe interpretation we propose, is associated with an actual clinical technique applied for diagnosis of ankylosing spondylitis, back strain related to primary osteo-arthritis and knyphosis. The possibility of using the gratings with changeable transparency is indicated.

Keywords: Moiré phenomenon; deformation measurement; human back

INTRODUCTION

The main goal of this paper is to study problems of a human back using a simple and useful optical technique. The majority of causes of the back problems are due to prolapsed lumbar intervertebral disc and osteoporosis-arthritis of the spine. Scoliosis is deformity or curvature of the spine. Structural scoliosis is caused by deformity of vertebrae. However, if the vertebrae are normal, the deformity can be caused by other reasons. It may be compensatory, resulting from tilting the pelvis from real or apparent shortening of one leg. It may be static due to unilateral protective muscle spasm, especially accompanying a prolapsed intervertebral disc. In structural scoliosis there is alternation in shape and mobility of spine constituting a deformity that cannot be corrected by alternation of posture. A careful examination is require to find a cause and suggest prognosis (Matula *et al.,* 2003; Hrazdira & Skotáková, 2006). Structural scoliosis may be congenital, deformity being due (for example) to a semi vertebra (only half of a single vertebra is fully formed, fused vertebra of absent or fused ribs). In paralytic scoliosis the deformity is secondary to loss of supportive action of trunk and spinal muscles, nearly always as a sequel to anterior polimeliomylitis. A cause for scoliosis could be due to disorders of the supportive musculature of the spine as well. Common cases of scoliosis leading to spinal deformity are accompanied with shortening of the trunk, and there is often impairment of respiratory and cardiac function (Liu & Chen 2004; Rousset *et al.,* 2000). This could lead even to invalidism and shortening of life expectancy.

Deformation of the back by spondylitis is due to progressive ossification of the joints of the spine. The joints between D_{12} and L_{11} are often affected, but the rest of the thoracic and lumbar spine is rapidly involved with striking loss of mobility. Stiffness of the back and pain are persisting symptoms.Tuberculosis of the spine is another cause of the back deformation and may produce angular deformation called kyphotic or scoliotic deformities. Beside the clinical observation, x-ray examination is the next procedure for investigation of a patient's back. The aim of this project is to introduce an optical nondestructive and noncontact technique to detect and identify the deformations of the back. The source of the apparent deformation of the back can be due to biomechanical deformities and muscle spasm.

In Fig.1. a human back and organs at the region of the back are shown. A pain of an internal organ can induce deformation of the back. While x-ray examination can identify the deformations of non transparent organs such as spinal cord, optical techniques such as Moiré can detect and quantify the deformation of the skin, deformations caused by internal organs or other biomechanical problems of the body.

Fig.1. Human back and organs at the region of a human back by Sebastian & Das (2011).

The advantage of the optical techniques, in this case of Moiré technique, is detection of in-plane and out-of-plane deformations. This is a robust, economical and simple technique that could be applied during the initial examinations of a patient. This technique is based on optical fringe formation and interpretation. However, it does not require a vibration free platform as in the case of holographic interferometry. Moiré approach proposed is based on harmless electromagnetic waves of visible region (Gomes *et al.,* 2010; Falcão & Udupa, 2000; Moran & Lipczynski, 1994).

Deformation measured by this approach gives us valuable quantitative information based on the fringe interpretation proposed by Takasaki (1970) for the first time, a clinical application of Moire' phenomenon using shadow contour Moiré technique. Since then there are many papers published on this topic.

Later on, Takasaki (1973) has improved his shadow-based contour Moiré by increasing the fringe contrast. The most comprehensive work related to medical applications of Moiré is one chapter of the book that can be found on Web in pdf form at the following address: *www.intechopen.com/download/pdf/36611*. The title is: "Moiré Topography: From Takasaki Till Present Day - InTech", written by Flávia *et al.* (2012). More than 80 authors and citations can be found at this chapter of the book. Here authors have elaborated thoroughly the Shadow-Moiré Technique. The projection Moiré is only mentioned with a picture obtained experimentally. The Moiré technique has been successfully used for medical applications in the past (El-Sayyad, 1986; Batouche *et al.,* 1996; Kim & Rodrigez, 2009; Roland, 1978; Richard, 1986; Kokaj & Li,1989). In this paper we have shown comprehensively, deformation measured of the human back: we have obtained the images and performed fringe interpretation using "Quick Fringe". As to our best knowledge, this software is used for the first time for fringe interpretation, when MT is applied for bio diagnosis of ankylosing spondylitis, back strain related to primary osteo-arthritis, and knyphosis medical deformation measurement. The MT measurement have limitations on detection of the mentioned deformations and health problems.

The advantage of our proposed method, capable to obtain simultaneously1-D, 2-D and 3-D representation with numerical data, makes our proposed technique useful**.** The software has possibility of applying so called horizontal and vertical centers, or they can be applied simultaneously. We have shown that the use of only horizontal centers leads us to optimal outputs. As is indicated by many authors, the most important element used in MT application is the optical grating. In case of shadow Moiré, only one grating is used. However, in case of projection Moiré, two gratings are used: object and reference grating. We have made and applied a new grating with linear changeable transparency.

While reading more than 70 references, we have notice that only static position and symmetry of contours have been analyzed by MT.

Here, we have studied several positions of the human body, simulating the dynamics of the motion. In collaboration with medical experts and by consulting books such as Clinical orthopedic examination (Roland McRae, 1978) and Management of the Back Pain (Richard, 1986) we have studied critical positions of the back of the patients. Beside clinical touch, doctors have used a flexible meter to obtain quantitative information to determine the deformations and diagnosis of Ankylosi spondylitis, Primary osteo-arthritis and kyphosis. A patient is asked to bend forward by sliding the hand down to the knee at different positions. They are asked to slide down the side, or rotate the shoulder while pelvis remaining at unchanged position. For all positions, using a flexible meter, measurements are performed and clinical estimation is reached.

Here, for the first time known in literature, we simulated the same positions and for each case Moiré measurement is performed. The main experimental element to perform MT-based measurement is a diffraction grating. We have made and applied diffraction gratings and performed image processing while applying coherent techniques, we have introduced before (Kokaj & Li, 1989; Kokaj *et a*l., 1997a; Kokaj *et a*l., 1997b; Kokaj, 2000; Kokaj, 1978). We have applied gratings with changeable transparency of their periodic structure. Using phase and changeable amplitude gratings, we have reached to shift the optical transmitted energy towards the higher diffraction orders or towards the higher frequency. At the same time, in the past, we have shown that by using higher diffraction orders, measurement accuracy and sensitivity can be increased. In case of MT application, by using higher diffraction orders fringe multiplications can be performed. In Section 3 of this paper, we have performed MT-based measurement by using a diffraction grating with changeable transparency.

In section 2, the concept regarding Moiré application is presented. The theory has been written down in the literature frequently, as it is a well established theory. The present work is exclusively about the experimental work, where Moiré fringes of human body have been performed and analyzed using fringe interpretation technique, where quick-fringe software has been used. Experimental results obtained by using projection Moiré are presented in Section 3, where typical cases of 3-D deformations are selected. Subsequently, the main results obtained for the human body at quantitatively determined position using two weighing scales and measurement of the distance of tip of the finger from the knee are presented at this section as well. The fringe interpretation using "quick Fringe " 1-D, 2-D and 3-D information.

MOIRÉ PHENOMENON

The Moiré figure can be obtained by superposition of two periodic structures. The periodic structures can be superposed to form a new pattern, with new periodicities in addition to those of the individual grids. In Figure 2 the schematic representation of the projection Moiré technique is shown.

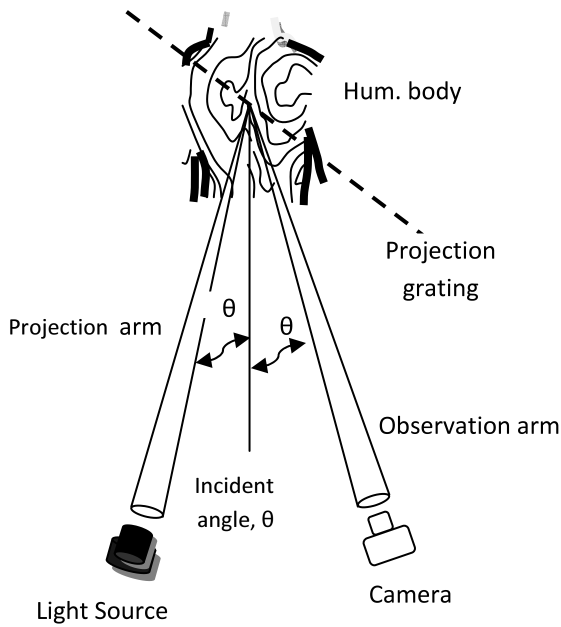

Fig. 2. Setup for projection moire

The projection arm with the light source and the observation arm with camera and the object are shown. The object here is a human back.

The newly obtained sub patterns shown in this figure are the Moiré lines. Coarse-structure components in these patterns can be extracted by low-pass filtering or visual observation. Information about the coarse moiré patterns of Fourier transform is contained in the low-frequency components of the Fourier transform of the complex structure. This transmission function is the product of the transmittance functions of the individual grids, and the transform of a product of functions is the convolution of their individual transforms.

Regarding Moiré theory, there are many books and mathematically instructive papers (Lohman & Sinzinger, 1993; Theocaris, 1969) that have explained mathematical concept of Moiré phenomenon M(x,y) and its application by using three steps:

a) Encoding the image to be studied I(x, y) into a distorted grating J(x,y),

b) Placing a second (reference) grating C(x,y) on top of the (object) image,

c) observing and interpreting the mo Moiré iré pattern represented by

$$M(x, y) = J(x, y) * (Cx, y)$$

The individual structures are characterized by three parameters: spatial frequency, orientation, and element profile (variable of the transmittance over one period). Moiré can be defined as the convolution or operation in which position vectors of the functions to be convolved are added vectorially, whereas the corresponding profile-shape transforms are multiplied. The transform of the single element of the pattern is usually called the diffraction function; the transform of its periodicity is called the interference function.

EXPERIMENTAL INTERPRETATIONS

Formation of the Moiré on a human back

Initially we have projected a grid on a human back. The body of a young man was placed in a position shown in Fig. 3. As is shown the vertical lines of the projected grid have different lengths according to the regions of the back.

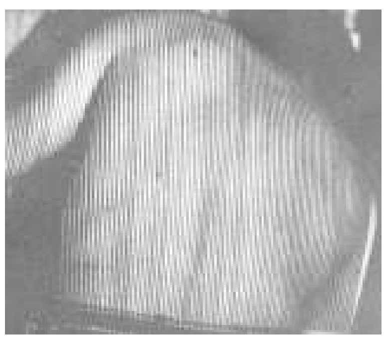

Fig. 3. Projection of a grid on the human back.

The grating used for projection is named as an object image. Using a source of light, the object grating is projected on the surface of a human back. As shown in Fig. 3 the image of the back can be considered as a new grating. The total structure of this grating is actually the same as the shape of the body. Therefore, any change induced on the back and defined as a deformation, could be measured by measuring the change of the newly obtained grating as shown in Fig 3. If the size of the body is increased, the distance between the lines of the projected grid is increased as well. Deformation induced on the body due to bending or twisting for a particular angle will cause change of shape of the grating as shown in Fig. 3.

Therefore, the distance between the lines, shape or constant of the projected grating is changed due to the deformation of the human back. The changed parameters of this grating that contain the information of the human back are visualized and quantified or measured, using Moiré phenomenon.

In case of Projection Moiré, we have used the setup shown on Fig. 2. The illumination angle is smaller than 90^0. A source of light is placed on one side, let us say on the left side of the line perpendicular to the surface of the body or object. A grating named as object grating is placed between the source and the body. On the other side of the normal to the surface of the object, at certain distance, is placed a camera. Between the surface of the body and camera, a grating named as a reference grating is placed. The superposition information of the grating projected on the surface and this grating named as the reference grating, generates Moiré figures that are photographed by the camera. We have performed Moiré by using the grating with a constant transparency and with changeable transparency. The results are shown in Fig, 4 and Fig. 5 respectively.

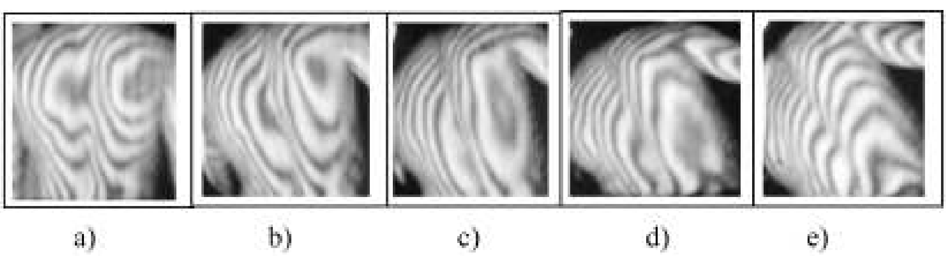

Fig. 4. Moire results obtained when conventional gratings are used.

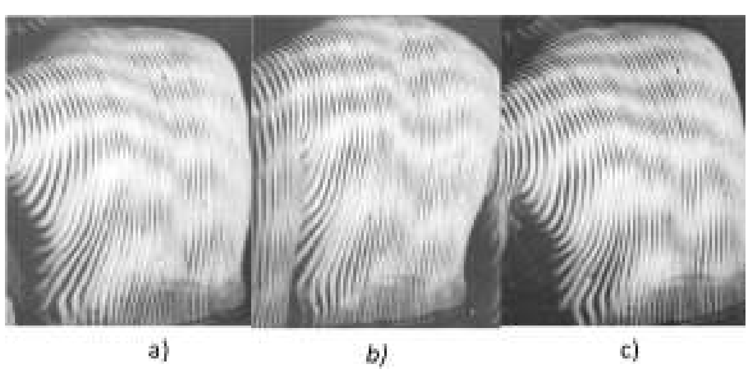

Fig. 5. Projected Moiré: when liner transparency of the grating is applied.

The case shown in Fig.5 will be studied in the future work. Here we study only the case when only conventional gratings are used.

A human is placed all the time at the same place and the source of light, grating in between the source and the body, the grating in front of camera and a camera is fixed all the time at the same place, while the body has changed positions by keeping the legs at the same position, in order to introduce deformations. To make this metrology technique more robust, the camera is not placed perpendicular to the plane of view.

Quantitative fringe analysis

In order to quantify and reach the reproducibility of the experiment, a graduate student active in sports is taken as a model for investigation. His back was towards us and his legs were placed on two scales. His weight was 81kg.

To determine the reproducible positions of the body, the student is placed with his two legs on two different scales. To simulate deformations, the weight is increased on the left leg and decreased on the right leg. At the same time the left arm is stretched vertically towards the left knee. Each subsequent phase of the human body, simulating the deformations, is imaged and measured by Moiré approach and quantified by fringe interpretation software.

For the fringe interpretation, for each position representing a particular deformation of the back, the same circle size and selection of the same part of the image of the human back is performed. On each image the same software and the same parameters are applied. Results of the fringe interpretation are presented in three different images shown beside the image of the back with Moiré fringes and the selected part of the back with the mentioned circle. The so called fringe centers represented by crosses within the circle are placed automatically by the software, ensuring the reproducibility of the same procedure for different images, representing deformations of the back. Next three images beside the image of human back and the circle containing the information only of the part of the body selected within the circle are shown. The first image, on the left top corner of this part of the back represents the contour representation obtained by the software. Second image shown on the right down corner represents one dimensional profile of the surface and fourth image on the right down corner of the main image, represents the three dimensional surface or deformation of the body. The fifth image is the so called fringe synthesis which can be used as additional information for the correct interpretation of the fringes and actual deformation of the back.

In Fig. 6 the human (a student) of weight 81kg is placed with two legs on two different scales. His weight on the left scale was 45.5 kg and on the left scale was 35.5 kg. On the left leg the weight is for 10 kg more than on the right leg. For this case, the Moiré fringes shown on the left corner of Fig 6.a, are not symmetric because the weight of the body including the trunk and back are not distributed symmetrically on both scales.

After the software for fringe interpretation is applied, contour, line profile and 3-D surface plot is represented in the Fig 6. b, 6. c, and 6. d respectively. Synthesized fringe representation is shown in the middle of the lowest row, Fig. 6. e.

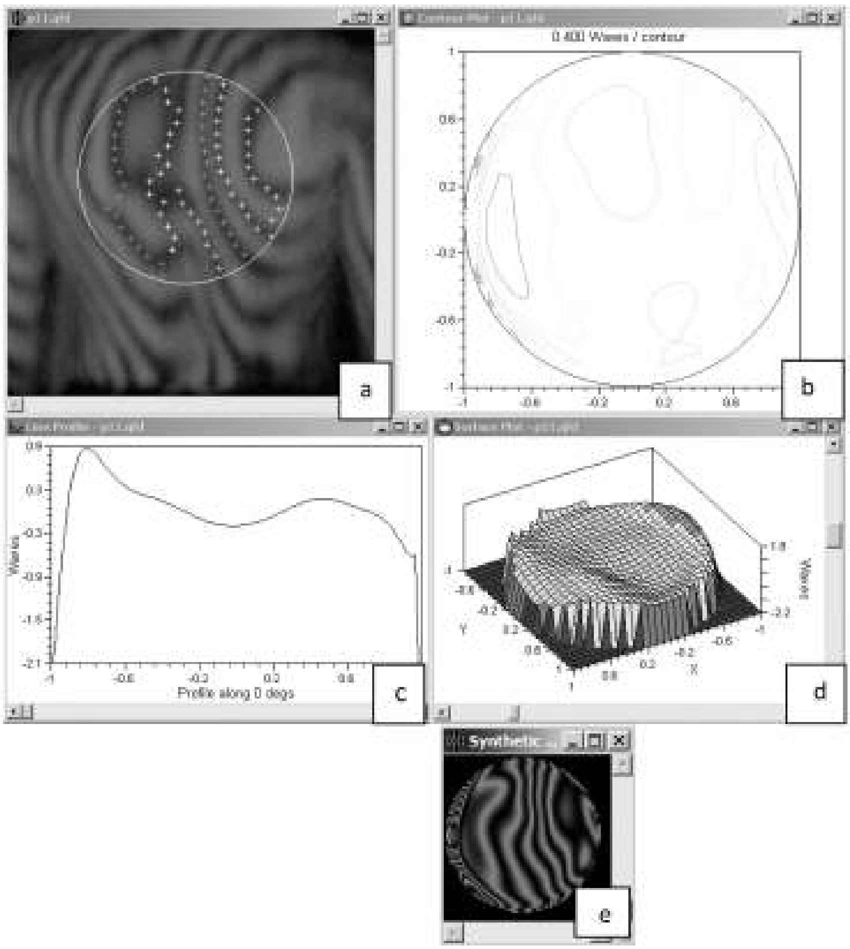

Fig. 6. The case when the weight on the left leg is shown to be 45.5 kg and on the right leg is 35.5 kg.

Contour representation obtained by the fringe interpretation software contains a low density of contours indicating that deformations are not emphasized in this case. This can be seen in the surface representation and one-dimensional so called wave representation. Two maximum points related to corresponding points on the human body selected by the circle can be seen. Otherwise, this graph is relatively flat compared to the next cases.

In the next experiment, the weight on the left leg that is measured by the scale is 55 Kg. The position of the body for this case and the Moiré fringes are shown at the upper left corner in Fig.7. a. After application of the software for fringe interpretation the contour, line, 3-D surface and synthetic representation are obtained and shown in the Fig. 7. b, Fig.7. c, Fig.7. d, and Fig.7. e, respectively.

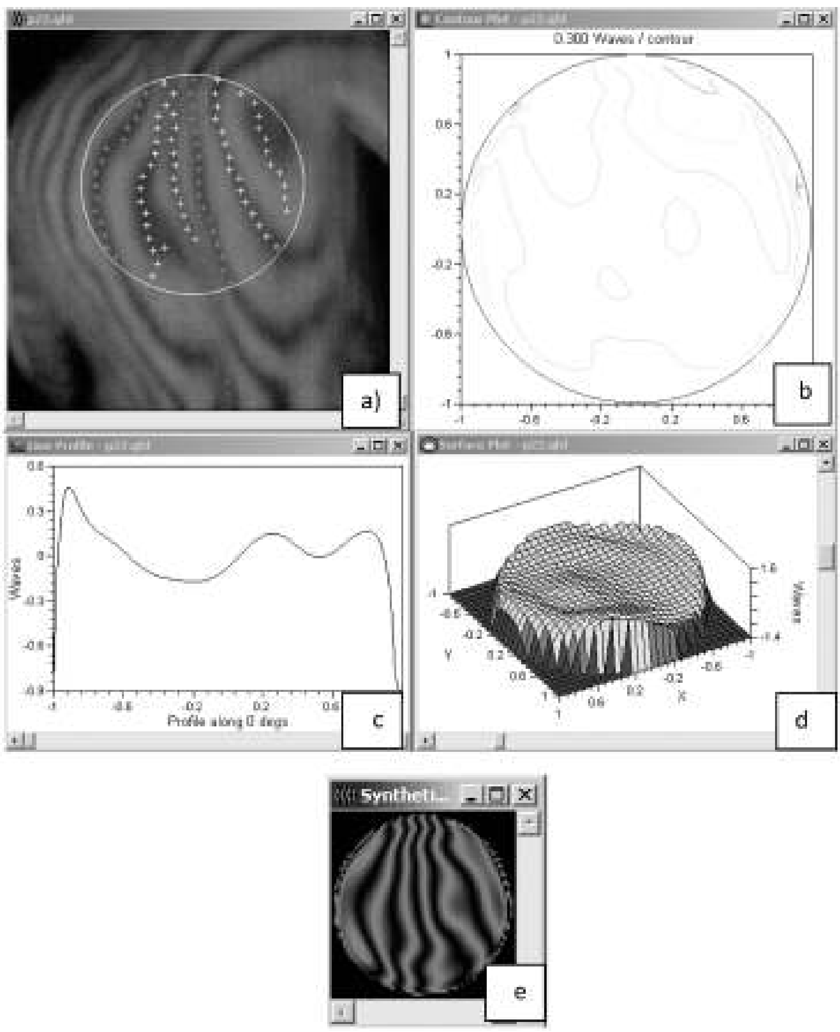

Fig. 7. The case when the weight in the left leg was 55 kg

When the weight is increased on the left leg that is measured 55 kg and the tip of the longest finger of the left hand is only 2 cm above the knee of the left leg. For this position more bending of the body has been required.

In Fig.7. a, is shown position of the body for this case. The Moiré fringes obtained for this case are shown as well. After the fringe interpretation is performed by the software, the contour, one dimensional line of the wave representation, 2-D surface representation and ynthetic representation are shown at the same figure 7. Here the density of the contours is increased, indicating an emphasized deformation of the back. Surface representation and 1-D wave show one maximum and one minimum beside the edges of the contour of the selected part for the human back.

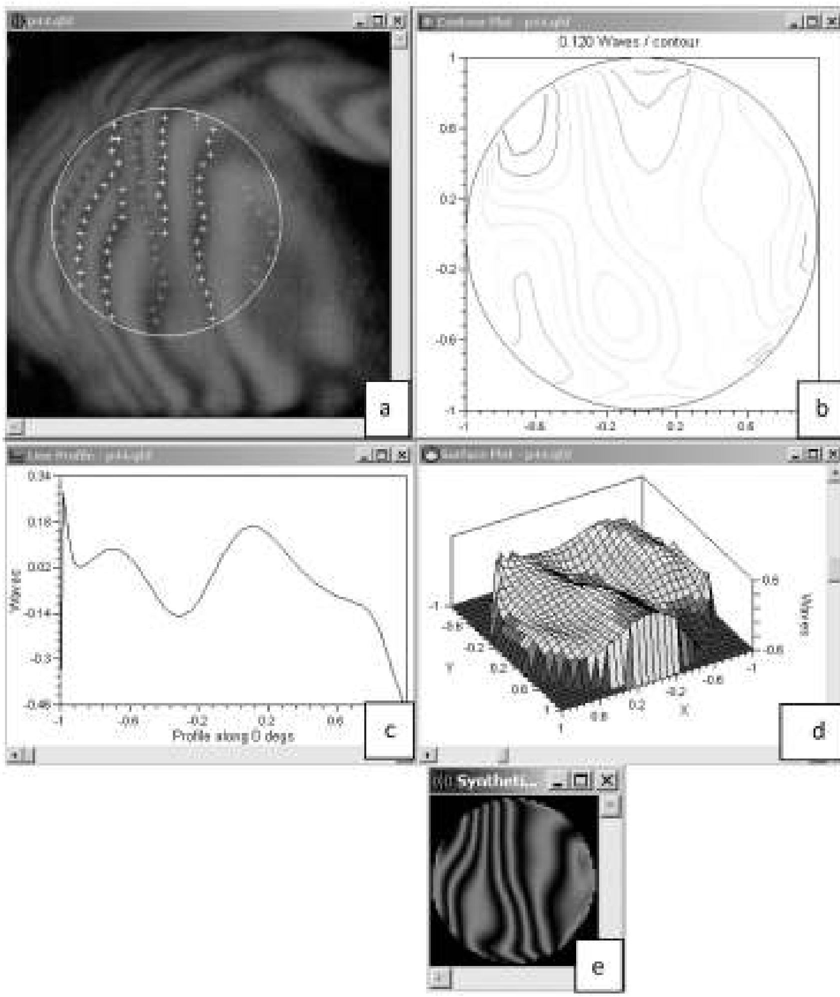

Fig. 8. The case when the weight on the left leg is 68 kg.

In case represented in Fig. 8, the weight on the left leg was increased up to 68 kg and the tip of the finger was on the top of the knee. As can be seen on Fig. 8 the shape of the contour representation is changed, indicating a more emphasized deformation of the body. In surface representation and particularly in the image of 1-D wave representation is shown so that two maxima and two minima are obtained. An image of an asymmetric distribution of the fringes is obtained when the fringes are synthesized.

Finally, the total weight of the body is placed on the left leg and is measured 81 kg. At the same time, the longest tip of the finger of the left hand is placed 3 cm below the knee. The position of the body for this case at the upper left corner is shown in Fig. 9. Obviously, in-plane and out-of plane deformation has been induced. Deformations are visualized by fringe contours that are obtained on the surface of the body. Analysis of the fringes is performed by using fringe interpretation software. Results for contour, line, 3-D surface and synthetic representation at the same figure are shown.

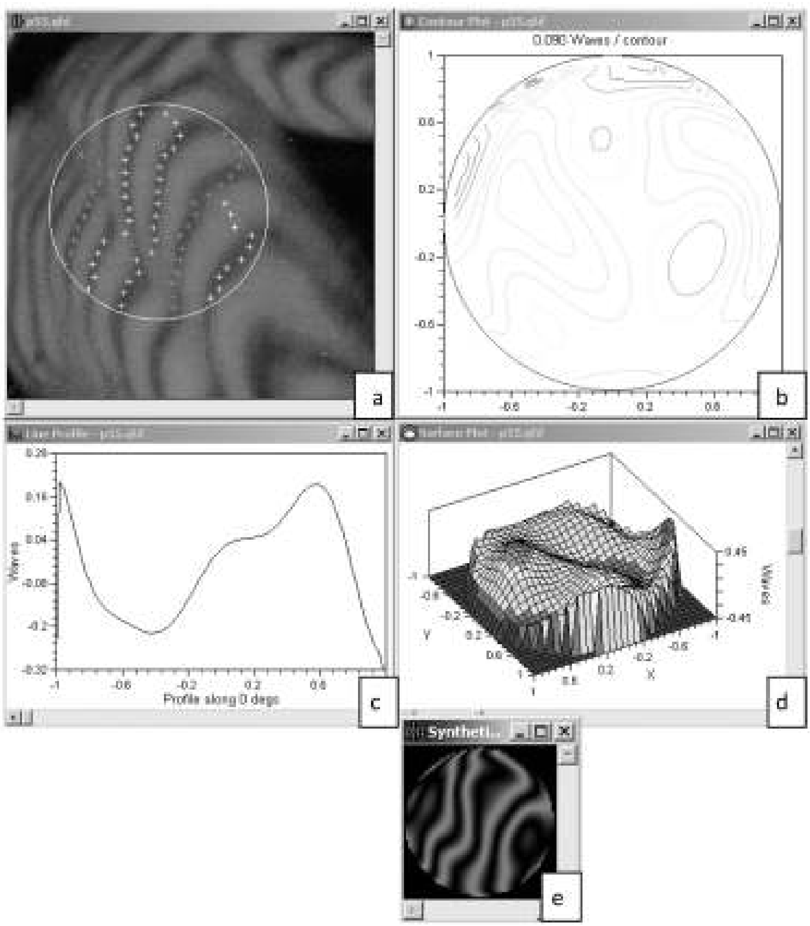

Fig 9. The case when the weight on the left leg is 81 kg.

Very emphasized deformation can be seen from the contour representation of this case as shown in Fig. 9. An emphasized minimum can be seen from the 1-D or wave representation of this figure.

CONCLUSION

Clinical investigation of a human back usually is followed by x-ray imaging. This procedure of medical checkup gives us only qualitative information. Moreover, x-ray radiation could cause serious health problems. Moire' Technique is a successful non destructive technique, applied for biomechanical application, where electromagnetic waves of longer and safe wavelengths are used.

Projection Moiré approach, proposed here, by using "Quick fringe" for fringe interpretation has some advantages compared to other techniques, when other softwares are used. Results obtained herewith contour 1D, 2-D and 3-D representations, give us information for in-plane and out-of-plane deformations.

The main role for successful application of MT plays the grating used and image processing performed. Based on our experience we had in the past, we made holographic, computer controlled and conventional gratings in order to choose the optimal experimental result. We have applied projection MT with conventional and holographic gratings with constant transparency or constant amplitude-based gratings. Moiré outputs are obtained and fringe interpretation is performed, while using those gratings. However, we used our computer generated gratings (CBG) with changeable transparency, so called amplitude and phase gratings. Results of Moiré are shown, when CBG are used. These are attractive, because it can be used to change the direction of the diffracted light of higher energy towards higher diffraction orders of higher frequencies. We indicate that the use of the selected higher diffraction orders can be used for multiplication of the Moiré fringes. The increase of measurement sensitivity and accuracy by using CBG will be our task of the future work.

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قياس تشوهات العمود الفقري باستخدام تقانة موير

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خلاصة

تستخدم تقانة موير لقياس درجة تشوه العمود الفقري. يتم تحديد موضع أجزاء جسم الإنسان بقياس وزن الجزء وكذلك المسافة من طرف اليد اليسرى إلى الكاحل الأيسر. بعدها تُسقط صورة الأجزاء باستخدام التقانة لكل موضع من المواضع. ويتم قياس درجة التشوه باستخدام ما يعرف بإسقاطات موير. كما يتم تحليل الأهداب الناتجة عن الصورة من خلال مقاربة الاسقاطات الميورية. باستخدام برنامج "Quick Fringe" الحاسوبي. يعدل البرنامج بحسب متطلبات التجربة. يمثل الخط الكفافي الإسقاطين أحادي الأبعاد وثنائي الأبعاد لأربعة أجزاء مشوهة في ظهر مريض. تستند معالجتنا للموضوع على مبدأ تكافؤ تقانة ميور بمصاحبة التحليل الهدبي مع تقانات التشخيص الطبي لالتصاقات إلتهاب العمود الفقري و توترات الظهر المصاحبة للروماتزم وكذلك تحدب العظام. ولزيادة دقة القياس وحساسيته نستخدم مستويات حيود أعلى بالإضافة إلى مقاربة مضاعفة الأهداب. وتبدو احتمالية استخدام محزوز الحيود متغير درجة الشفافية جيدة.