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# Defining of the Shape of the Spine Using Moiré Method in Case of Patients with Scheuermann Disease

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***Abstract*****—**Nowadays spinal deformities are very frequent problems among teenagers. Scheuermann disease is a one dimensional deformity of the spine, but it has prevalence over 11% of the children. A traditional technology, the moiré method was used by us for screening and diagnosing this type of spinal deformity. A LabVIEW program has been developed to evaluate the moiré pictures of patients with Scheuermann disease. Two different solutions were tested in this computer program, the extreme and the inflexion point calculation methods. Effects using these methods were compared and according to the results both solutions seemed to be appropriate. Statistical results showed better efficiency in case of the extreme search method where the average difference was only 6,09°.

***Keywords*****—**Spinal deformity, picture evaluation, moiré method, Scheuermann disease, curve detection, moiré topography.

## I. INTRODUCTION

MEASUREMENT of diffusely reflecting surfaces are important topics in contemporary measurement techniques. From these optical measurement methods rapid and effective tools of three-dimensional surface metrology evolved. Examples of applications are widely used in industrial inspection of manufactured parts, object recognition and orthopedic inspection. The best known methods that can be used for optical three-dimensional measurements on diffusely reflecting object surfaces are the profilometric structured light and moiré methods [1]. Moiré topography methods are applied in automatic inspection systems, when measurement with mechanical methods cannot be carried out. It is also suitable to classify products made in robotized production [2]-[4]. In the field of orthopedics, moiré imaging is considered to be suitable to measure and graphically display whole surfaces instantaneously. Consequently, it is used to examine foot and spinal deformities, but this optical method is one of the most modern ways for measuring the spatial shape of the human body [5], [6]. The advantages are the simultaneity and the non-contact way of the measuring so it does not influence the analyzed body. Furthermore, information was obtained from all points of the analyzed surface at the same time.

## II. SPINAL DEFORMITIES

### A. Description of Spinal Deformities

Spinal deformities are originated from unknown genesis. There are two big types of spinal deformities, the one dimensional Scheuermann disease, and the two or three dimensional idiopathic scoliosis. In this paper we solely deal with the Scheuermann disease. It is a very frequent problem among 10-17 years old children. According to the literature data 11% of children are concerned.

### B. Scheuermann Disease

In case of this disease the spine is straight in the frontal plane, but the thoracic kyphosis is much rounder, (or a kyphosis is formed on the lumbar part of the spine) than at healthy people [7]. It is not easy to diagnose the Scheuermann disease, because slightly rounder kyphosis is usually inconspicuous. Often negligent posture is diagnosed instead of Scheuermann disease and deformation remains without a suitable treatment. For screening the disease first a physical examination type –Adams test has to be used. During this examination patients have to bend forward with provided arms. If the round kyphosis cannot be straightened in this position, Scheuermann disease is diagnosed. After screening, patients have to go to an X-Ray examination for checking the shapes of the vertebrae. In general on the inner side of the spine the shapes of vertebrae are changed. This deformation can be visible on X-Ray images. In case of the disease vertebrae are lower in the inner side and the collagen combination can be changed in the endplates, so the cartilage rift can be tight between the vertebrae. If there are three deformed vertebrae next to each other in the X-Ray picture, the Scheuermann disease is proved. Seriousness of the disease can be determined using the medical method: measuring Cobb-angles from the X-Ray images.

### C. The Cobb-angle

The Cobb angle is measured on radiographs by drawing a line through the superior endplate of the superior end vertebra of a weed curvature, and another line through the inferior endplate of the inferior most vertebra of the same weed curvature (the rounder kyphosis) then measuring the angle between these lines. [8], [9]

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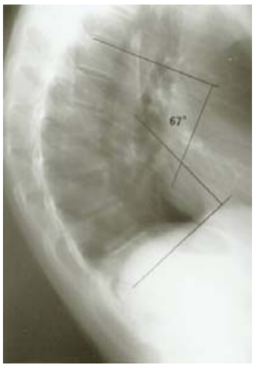

Fig. 1 Measuring Cobb-angle in the sagittal X-ray picture [10]

### D. Treatment of the Disease

Patients diagnosed with Scheuermann disease have to do physiotherapy and/or wear Gschwend brace as a part of the treatment.

In case of slight deformation patients have to do only physiotherapy at home, minimum 5 days per week. If the physiotherapy itself is not enough, patients have to wear rigid polyethylene equipment, the brace. The Gscwend brace has a thoracic pressure surface, which can push the weed kyphosis into the right position.

In case of lumbar kyphosis the Boston corset has to be worn. This equipment is tighter and put pressure on the lumbar part of the spine.

Both devices have to be used until the end of ossification.

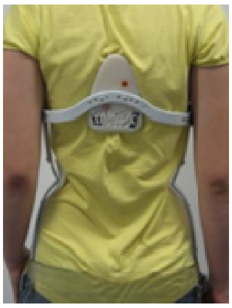

Fig. 2 Gschwend brace [11]

## III. THE OPTICAL DEVICE USED DURING THE RESEARCH

X-Ray radiation is harmful for the human body, especially for children. There are some attempts for eliciting this dangerous diagnostic method. Equipment based on a similar optical method was used during the examinations.

The moiré phenomenon is the result of the interaction of two periodic structures [14]. This phenomenon is known as a moiré fringe pattern. This pattern contains a system of dark and bright strips. In practical applications bright strips are called moiré fringes [12]. The spacing and orientation of the moiré fringes depend on the behavior of the base structures [1]. It means that the moiré stripe is the manifestation of the moiré phenomenon. The moiré based representation of the measured or tested surface is similar to the contour lines of the maps but described in more general form [15].

Two gratings are necessary for generating moiré fringes, one specimen and one master grating. The gratings are characterized by its spatial frequency that is the number of lines per unit length [16]. Superimpose of the master and the deformed grating produces system of moiré fringes that describe constant out-of-plane depth.

A widely used technique of contour mapping is the projection moiré method. In case of a projection moiré equipment a grating is projected onto a specimen and this deformed structure is observed through the reference grating. In electronic projection-type equipment the projected and the master gratings are electronically generated and the moiré pattern is the result of a computational process in the memory of the computer. This means complete independence of both gratings in amplitude and phase [17] that allows flexible follow-up adjustment by processing of measured data [18]. The electronic projection moiré equipment is modified classical projection moiré equipment that contains a computer controlled projector connected with a digital camera [19]. The captured images are processed using virtually generated reference grating in the memory of the computer.

## IV. EVALUATION OF THE MOIRÉ PICTURES

For the determination of the Scheuermann disease from moiré pictures a software has been implemented in LabVIEW programming environment with the Vision & Motion Toolkit distributed by National Instruments.

By evaluating the moiré pictures the most important is to get the altitude information from the 2 dimensional pictures. The solution is as follows.

The first step was to prepare the chosen moiré picture for evaluation; the useful area of the picture had to be trimmed. In this part of the picture an auxiliary mesh was created. After selecting a horizontal mesh line, intersection points had to be recorded with the moiré fringes. Using these intersection points an $n^{th}$-order fitting curve was calculated for defining a point from the spine line. Two different mathematical methods were implemented into the program to get the points of the spine line. The first method used the calculated inflexion points while the second one utilized the extremes of the fitted polynomial.

For the inflexion point search algorithm it was important to find the inflexion points of the polynomial next to the valley of the back. The program generated two tangential lines based on the identified points. The intersection of these lines represented a point from the spinal curve.

The extreme search algorithm had to find the extremes located in the valley of the back. This point could be used as a part of the spine line. The final shape of the spine could be obtained by executing this algorithm in every horizontal mesh line between two chosen vertebrae, the cervical 7th and the lumbar 5th. After evaluating all of the horizontal mesh lines another curve fitting method had to be used to get the shape of the spine, on the perpendicular surface to the plane of the moiré image (sagittal plane).

The following sections explain the steps being executed on a horizontal mesh line in order to fully understand the functions of the software.

### *A. Image Preparation before Evaluation*

The evaluated moiré picture had to be loaded into the program and an informative area had to be selected from it. This part of the picture contains the necessary information for detecting the curve of the spine. The necessary information hailed from the moiré fringes.

By measurement, before taking the moiré picture two markers were glued on the patient's back to indicate the important vertebrae for the evaluation. Markers were LED light sources; they were pasted on two well touchable vertebrae, on the cervical 7th (C7) and on the lumbar 5th (L5). These markers helped to fit the generated spine line into the X-Ray picture of the original spine to check the rightness of this solution. These markers were visible on the moiré picture and were used for marking the starting and the endpoints of the generated line.

### *B. Mesh Generation*

After the preparation an auxiliary mesh had to be generated. The intersection points of the mesh and the moiré contours gave the altitudinal information. The mesh creation was based on the horizontal, the vertical resolution of the picture and on a grid size constant which set the desired size (in pixels) of a grid.

The aforementioned intersection points had to be selected with a mouse click. The program checked the coordinates of the mouse click in the picture and selected the closest horizontal and vertical mesh line crossing point. The grid size was very important because of this notation. If the grid size is large, the result can be inaccurate. Using smaller grid the mesh could be denser with more horizontal and vertical crossing points. The result is a better approximation.

To get the height data the intersection points had to be weighted. The weighting was calculated by multiplying the order of the moiré fringe with a constant (during the development this constant was 5). In this case the highest (the innermost) contour lines gave the largest weights, and the lowest ones (outermost contours) get the least orders. At the end of the acquisition of the intersection points, the resulted weightings were added to the ordinates of the points.

Onto the intersection points an nth-order polynomial curve had to be fitted. Usually a maximum 5th order polynomial was used because of the physiological shape of the back.

The LabVIEW development system offers several built-in fitting processes. The built-in general polynomial fitting method was used during the whole development operated with Cholesky-algorithm.

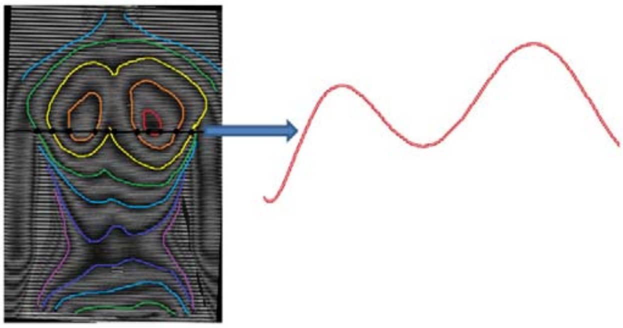

Fig. 3 The selected horizontal grid after curve fitting [5]

Two determination methods were implemented for defining the spinal curve. The first one calculate the inflection points, the second one find the extremes of the fitted curve.

These steps have to be done on all horizontal mesh lines. At the end of this examination a set of points were received. A polynomial had to be fitted onto these points to get the searched spine line. The generated line was on the perpendicular surface to the current plane of the image.

For the evaluation of the pictures it was important to use only one selected method as the mixing of the methods could cause inaccurate results.

### *C. The Two Examination Algorithm*

The first method was based on the extremes of the fitted polynomial. To locate extremes of a polynomial function, it had to be differentiable two times. If there was a solution to zero in case of the first derivate there was an extreme at the resulted abscissa value. To valid the exactness of the calculated extreme the ordinate value had to be calculated after substitution. The processed extreme was a part of the spine line in the middle of the valley of the back.

The second method was based on the inflection points of the fitted polynomial. In this case, the polynomial needed to be differentiable two times as well. For the locations of the inflexion points the second derivative had to be checked. According to the description of the first method the produced inflexion points had to be checked.

The two selected inflection points had to be located next to the valley of the back. In these points the algorithm created two intersecting tangential lines. This intersection point was used as a point of the spine line.

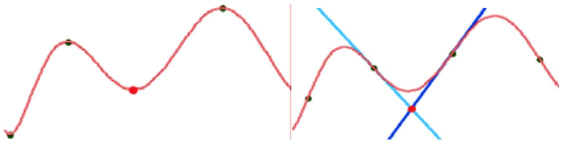

Fig. 4 Mapping nonlinear data to a higher dimensional feature space

These steps were executed on every horizontal mesh lines. After these steps the points of the spine on the sagittal plane could be determined. To generate the spine line a polynomial fitting method had to be performed as well. A built in, general polynomial fitting method could be used here as well, but because of the sagittal physiological shape of the spine a 3rd order curve could be used.

## V. RESULTS

### A. The Evaluated Pictures

11 moiré pictures of patients with Scheuermann disease were evaluated. Both of the before mentioned methods were tested and compared to each other. After evaluation results were compared statistically.

For validation of the two methods the before taken X-Ray pictures and the markers of the moiré images were used.

The two spine lines using the two different methods approximate the original spine visibly well but there were some differences in the statistical results.

After fitting the generated line in the X-Ray pictures the measured – derived from the generated spine line – and the original– derived from the Cobb-angles – Cobb-angles were compared to each other. The original values derived from an orthopedist and the measurement based on the original definition of Cobb-angle where the borders of the vertebrae and the inflexion points of the generated line was used. In this way we got three groups. These results were compared in pairs to the medically derived Cobb angle.

TABLE I
COBB-ANGLES USING THE ORIGINAL MEASURING METHOD AND OUR TWO SOLUTIONS

| Patients | Medical Cobb-angles | Extreme search method | Inflection point method |
|---|---|---|---|
| *1* | 44 | 48 | 61 |
| *2* | 53 | 52 | 60 |
| *3* | 61 | 71 | 52 |
| *4* | 27 | 32 | 41 |
| *5* | 31 | 32 | 51 |
| *6* | 55 | 67 | 79 |
| *7* | 12 | 21 | 42 |
| *8* | 26 | 31 | 44 |
| *9* | 34 | 38 | 36 |
| *10* | 35 | 48 | 51 |
| *11* | 58 | 63 | 63 |

### B. Statistics

As Table I shows the medically generated Cobb-angles were in good agreement with the results from the tested two methods (5° margin of error to be considered using the medical method). Calculating the mean difference between the extreme method and the medical method the result was 6.09°, in case of the inflexion point search and the medical method the mean difference was 13.09°. In this way the extreme method seemed to be more suitable.

For better analysis Pearson correlations were used to compare our two methods to the medical results. The extreme method results showed also better conformity to the medical Cobb-angles using this examination. In the case of extreme method Pearson r was 0.9633. This result gave better accordance than the inflexion point search method compared to the medical results, where Pearson r was only 0.7158.

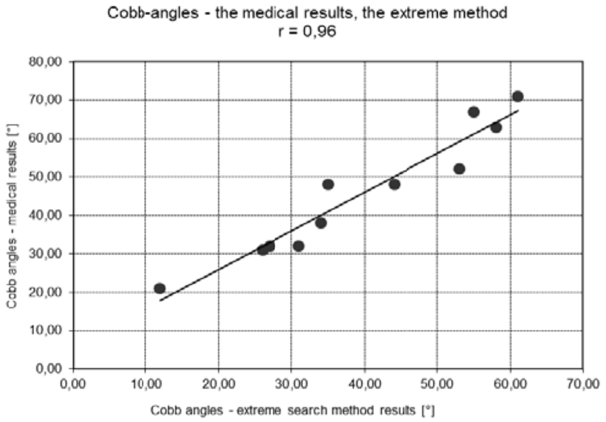

Fig. 5 Extreme method Cobb-angles compared to the medical Cobb-angles with Pearson Correlation

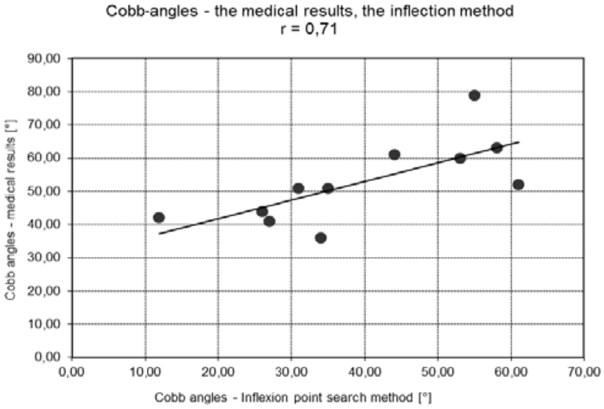

Fig. 6 Inflexion method Cobb-angles compared to the medical Cobb-angles with Pearson Correlation

In the statistical analysis the following examinations were the paired t-tests between the two methods and the medical Cobb-angles. These examinations showed similar results than the previously described outcomes. The inflexion point method comparison to the measured Cobb-angles using the medical method the p value with paired t-test was 0.0028. The extreme search method comparison to the medically derived results the p value was only 0.0010. The examination showed no significant differences according to the medical results neither in case of the extreme method nor the inflexion method, but the conformity is much better using the extreme search method.

According to these statistical results the extreme search method proved to be more effective than the inflexion point search method.

This statistical difference is not justified, because on the X-Ray images both lines fitted visibly well on the original spine. The reason of the difference hasn't known yet, but there are some opportunities: for example the huge muscles on the lumbar part of the spine can cause some difference in case of the inflexion method. Tangential lines of the lumbar part are much steeper than on the kyphotic part of the back, so intersections of tangential lines arise deeper than the original vertebrae are. This phenomenon can cause a not too large difference between the generated and the original shape of the spine.

## VI. CONCLUSION

It is important to deal with these results because nearly 11% of children are concerned with Scheuermann disease. In the literature not any modern research can be found about solving this problem, but there are a lot of different studies about scoliosis screening and diagnosing [13]. It should be mentioned that there are much less affected patients with scoliosis. The concerned group is 2-4% of the children.

From the moiré pictures taken from the frontal plane the sagittal spineline can be produced using mathematical methods – as written in this paper. In this way these methods are useful for screening the Scheuermann disease. A rudimentary Cobb-angle could be generated from the moiré pictures without using any harmful radiation. In case of this examination screening is non-contact – compared to the spinal mouse [20] - and also comfortable. It can be repeated any number of times. Positions of the points of the back are fixed at the same time, so the error because of children's movement can be minimalized.

Both evaluating method used seem to be right, because there were not any significant differences between the Cobb-angles from the developed methods and the medical results.

The better solution was the extreme search method. It was proved statistically using three different measuring methods.

To verify the methods and get more accurate results it is very important to evaluate more moiré pictures.

To increase the reliability and the image processing time of the moiré pictures, it is necessary to have a higher degree of automation in the software. During this development the first task is to carry out the automation of the transverse mapping step. The system has to do automatically the intersection point generation on all horizontal lines, the weighting of the points using the orders and the polynomial fitting. The realization of this development can be eased by the Wavelet-transformation of the moiré fringes because using that mathematical method the fringes could be transformed into a continuous contour line. So the intersection point generation could be more accurate.

The weighting of the fringes could be more exact and accurate if the level difference of the fringes could be defined. This measurement is not a difficult correlation using the properties of the projection moiré device; it is planned to be done later.

Checking the shape of the detected curve could be more efficient if the generated $3^{rd}$ order polynomial can be fitted in the X-Ray images without any user instructions.

The implementation of the Cobb-degree calculation algorithm will be essential because of the further research plans.

After the complete development method has ended the software could be extended to detect 3D deformations (vid. scoliosis) and to create a full-scope diagnosis of the patient completing the medical technology with more artificial intelligence.

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