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Spineline detection with image evaluation

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***Abstract*— In case of screening and tracking conditions of patients [20] with spinal deformities it is very important to develop an examination method that does not load patinets' body with harmful radiation. This method is based on the moiré effect. Pictures were taken from patients' back and information could be obtained about the back's condition.**

A computer algorithm is under development that can produce the sagittal line of the spine from moiré images. This program is being tested with Scheuermann disease patients.

Keywords—computer algorithm; spinal curve; detection; moiré method; evaluation

I. Introduction

Identification and reconstruction of so-called free form surfaces are important topics in computer aided measurement technique. 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 object surfaces are the interferometric, structured light and moiré methods [11]. These are based on non-contact procedures and have different working ranges and sensitivities. Moiré topography methods are widely used in automatic inspection systems, when measurement with mechanical methods cannot be carried out. They are also suitable to classification or check spatial location and dimensional accuracy of products made in robotized production [12].

Moiré method is a time-honoured technology; it is applicable for the examination of symmetry and height differences [19]. That's why it is applied in the field of plastic surgery and orthopedics. Now - against the simple optical shadow moiré - the computer-controlled moiré photographing is used by us, and our system is applied for screening spinal deformities in case of children, and following their conditions during the treatment. Unfortunately until this time there were not any opportunities to evaluate these moiré photographs authentically, so the method was enough only for subjective comparison during treatment. These pictures are taken more often, than X-Ray images, so changes in conditions can be visible faster.[21] The only problem was, that the rate of the change was not visible. A suitable computer program is being developed by us, which is useful for determining the spinal deformities, and using this program following patients' conditions is much easier.

The object of our research is to produce a spineline using our computer program, which approximates well the real shape of the spine. Using this spineline a Cobb angle can be granted which is informative for orthopedists, and can be comparable with the medical values.

II. Spinal Deformities

There are two large different types of spinal deformities, according to the direction of the abnormal curvatures of the spine. Spinal deformities can be divided in one, two and three dimensional deformities.

A. Scoliosis

Scoliosis is a weed deformity of the spine. This type of the disease can be visible mostly in the frontal plane. It can be divided further into two different types, *functional* and *structural* scoliosis.[23] In both cases there are weed lateral deformities on the spine, but in case of functional scoliosis there isn't any rotation on vertebrae. Rib deformations cannot be observed instead of structural scoliosis, so it is not easy to be diagnosed. Luckily the formed abnormal curvature is not deteriorates without treatment. It can be cured effectively with physiotherapy. Asymmetrical strengthening of the back muscles is a good solution to stand weed curvatures into the right position.[22]

Functional scoliosis can be divided into primer and secunder scoliosis. If there is a motive, for example patients have difference between the two legs, weakness in their muscles, nerve defects it can be diagnosed as a secunder scoliosis. It is very important to find and cure properly each case for the successful treatment. Without any visible cases the disease can be diagnosed as a primer scoliosis.

In case of structural scoliosis there are weed lateral deformities on the spine with torsion. Cases have not been found yet to explain the development of the disease. Dispersion is not equal between the two genders. Young girls are twice more often concerned compared to boys. It could be discovered in rapid growth phase of the bones, mostly at teenagers (10-17 years old children). Sometimes there are 3-4 years old little children with large deformities who have to wear the brace until the end of ossification.[22]

Vertebrae torsion can cause rib deformations which is visible on patients back. Nowadays patients' physiological sagittal curvatures seem to be reduced (flat back). In case of structural scoliosis patients have to wear brace until the end of ossification without this the disease is going to deteriorate. In case of teenager girls the ossification ends about two years after the first menstruation. To verify the end of ossification X-ray images have to be taken. The developed Rissel mark on the pelvis shows us the end of the treatment. Serious scoliosis - without treatment, at adults - can cause pain, aesthetic problems, disability and even failures in blood circulation.[22]

The Cobb angle is measured on plane radiographs by drawing a line through the superior endplate of the superior end vertebra of a scoliotic curve, and another line through the inferior endplate of the inferiormost vertebra of the same scoliotic curve then measuring the angle between these lines.[1][2]

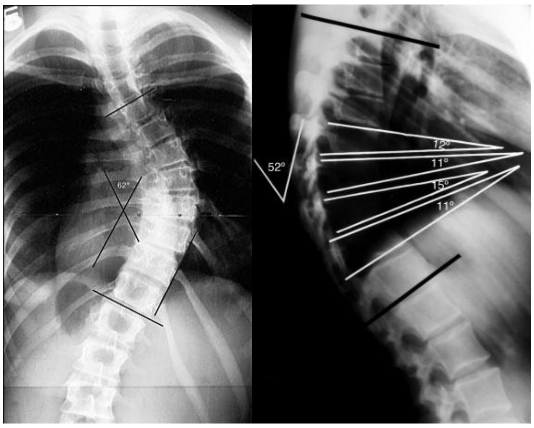


Fig. 1. Measuring Cobb-angles a.) from the frontal X-Ray picture (in case of scoliosis) b.) from the sagittal X-ray picture (in case of Scheuermann disease) [10]

B. *Scheuermann disease*

The second type of spine deformity is the *Scheuermann disease*. In case of this disease the spine is straight in the frontal plane, but the kyphosis is much rounder than at healthy people. Nowadays the lumbar kyphosis is also very frequent, which can be originated from the sedentary lifestyle (but this hypothesis has not been proved yet). [22] Often negligent posture is diagnosed instead of Scheuermann disease, and it remains without a brace and a suitable treatment. To establish the right diagnosis, it is important to use a physical examination type – named Adams test. Using this test patients have to bend forward with provided arms. If the round kyphosis cannot disappear in the examined position the Scheuermann disease is diagnosed. In general shapes of vertebrae change on the inner side of the spine. It can be visible also on X-Ray images. After the positive Adams test an X-Ray image have to be taken from patients' spine. In case of the disease vertebrae are lower in the inner side and the collagen combination is changed in the endplates, so the cartilage rift becomes tight between vertebrae. If there are three concerned vertebrae next to each other on the X-Ray picture, the Scheuermann disease is proved. Patients have to do physiotherapy and wear GSchwend brace as the part of the treatment.

Fig. 2. Scheuermann disease [9]

C. *Treatment of the spinal deformations*

Treatment method has to be chosen according to the condition of the disease (in case of scoliosis).

Under 20 degree Cobb physiotherapy can be sufficient. During the treatment muscles are strengthened asymmetrically, so they can keep the weed curvatures in the normal position. A few special exercises have to be practiced 5 to 7 times a week to get improvement.

Between 20 and 50 Cobb^{0} special *Schroth physiotherapy* have to be combined with *brace treatment*. The brace is a rigid, uncomfortable device. It puts pressure on the trunk to upright carriage. Opposite of this pressure there have to be formed moving areas, because of the movement of the trunk. It stimulates patients to use their own muscles, as they try to get into a position where they don't feel pain. It is important to do also physiotherapy next to the rigid corset treatment. Doing other sports (swimming for example) with brace is also recommended as muscles of the spine get stronger asymmetrically, just like with physiotherapy. [3-8]

Patients with scoliotic curve have to wear the Cheneau type corset (20-22 hours a day). Scheuermann disease patients have to wear GScwend brace. It is lighter and put pressure on the trunk only in one dimension.[22]

Fig.3. a.) Cheneau brace b.) GSchwend brace [9]

Above 50 degree surgical consultation shall be needed. In case of a considerable deformity with large rotation the spine has to be stretched a few weeks before the operation. Under the operation surgeon lay a metal device onto vertebrae and connect it with the spine. This device removes weed curvatures and keep the spine in a fixed position. It is only suggested in case of a very serious disease.[23]

III. Moiré Method

The moiré phenomenon is the result of the interaction of two periodic structures [13][21]. It is observed as a space modulated intensity pattern consists dark and bright strips. The moiré pattern is a system of the bright strips that are called moiré fringes [3][21]. 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 [4]. The moiré lines connect the points of a surface with a constant distance from the reference plane and this distance depends on the parameters of the layout geometry.

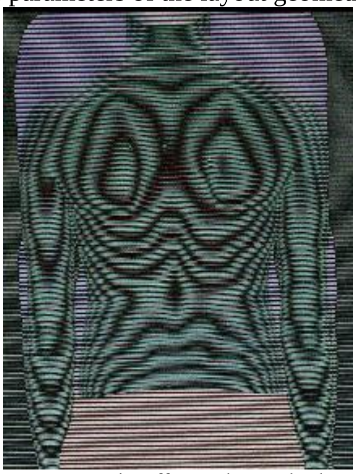


Fig. 4. Moiré effect on human back

A. *Geometric interpretation of the moiré phenomenon*

There are some ways to describe the appearance and behavior of the moiré phenomenon. The widely published geometric interpretation [15] is advantageous to understand the possibility of its application to solve different non-conventional *measuring tasks*. In this sense the spacing and orientation of the moiré fringes depends on the spacing and orientation of the base structures [15].

Two gratings are necessary to generate moiré fringes, a specimen and a master grating. Gratings are characterized by its spatial frequency that is the number of lines per unit length. By using the shadow moiré arrangement moiré fringes are contour lines of equal depth generated by superimposing a physical grid and its shadow projected on the examined surface. In practical applications, the examined specimen is positioned in front of a grating that is illuminated. The shadow of the grating is projected on the surface of the specimen [16]. Interaction of the grating and its shadow produce system of moiré fringes that describe constant out-of-plane depth.

The projection moiré method is another surface contouring method. According to this method with optical imaging a grid is projected on the examined surface (or specimen). A deformed grid has been generated which is contemplated during the reference grating.

Using electronic projection moiré equipment the projected and the master gratings are electronically generated. A moiré image has been created during a computation process using the memory of the computer.

This means complete independence of both gratings in amplitude and phase [11] that allows flexible follow-up adjustment by processing of measured data [14].

In all moiré techniques the surface height is measured relatively to a reference surface that is a plane if the reference gratings are straight and equally spaced. In the projection moiré equipment using the second grating allows modifying the reference plane [17]. The main difference between projection and shadow moiré is that two different gratings are used in projection moiré thus the degree of binding between the phenomenon and the observing grating is lower [18].

The electronic projection moiré equipment is modified classical projection moiré equipment that consists a computer controlled projector connected to a digital camera. The captured images are processed using virtually generated reference grating in the memory of the computer. [21]

IV. Program of the Evaluation

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. The best choice for this task was LabVIEW because it is a graphical (higher-level) programming language, and besides of the greater traceability and improvability, the available palettes of functions mainly simplify the implementation of the algorithms. Additionally, the Vision & Motion Toolkit can create layers on the pictures during the image evaluation and several auxiliary point and area can be defined as well. These objects are called in LabVIEW as Region of Interest (ROI).

To reach the main objective, the first step was to acquire the shape of the spine by the evaluation of moiré pictures. The interesting question in this step was how to convert the altitude information of the moiré picture into an exact, a further processable result. The solution is as follows.

After preparation of a moiré picture an auxiliary mesh was created on a layer of loaded image. After selecting a horizontal mesh line, intersection points with the moiré fringes were recorded. These points were used to calculate an n^{th}-order fitting curve, a polynomial. It was a basic point of the spine. Two mathematical methods have been implemented to get the in question point. The first calculated inflection points, the second one the extremes of the fitted polynomial. The inflection point algorithm selected those inflections which were located in the valley of the back. After this, the program generated two tangential lines based on the selected points. The intersection of these two lines gave a point of the spinal curve. The extreme calculation algorithm selected that extreme of the fitted polynomial which was located in the valley of the back as well. This point was a part of the spinal curve. The final shape of the spine could be obtained by executing this algorithm on every horizontal line of the mesh which was created at the beginning of the method. At the end a curve fitting method need to be executed to get the curve of the spine on the surface perpendicular to the moiré image evaluation surface (sagittal plane).

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

A. Image preparation for evaluation

At the beginning of the process a moiré picture need to be loaded. During the loading process two image preparation operation was executed. The first one converted the image into HSL representation which is the cylindrical-coordinate representation of the point in an RGB color model. After this, the luminance (L component) was extracted from the picture, so the result was a grayscale moiré picture. After these operations an area need to be selected which contained the necessary information for detecting the curve of the spine – the moiré fringes of the back. This area was selected manually with a ROI rectangle (or any other polygon). After the selection a cutting method was applied on the picture.

Because of the experimental set-up it might be occurred that the taken image was oblique. To correct this mistake the image could be rotated with an adjustable angle value (in degrees) before further processing operations.

In the picture two markers could be seen. These markers (after the computerized recognition) helped to determine those vertebrae which are start and endpoints of the determined curve of the spine.

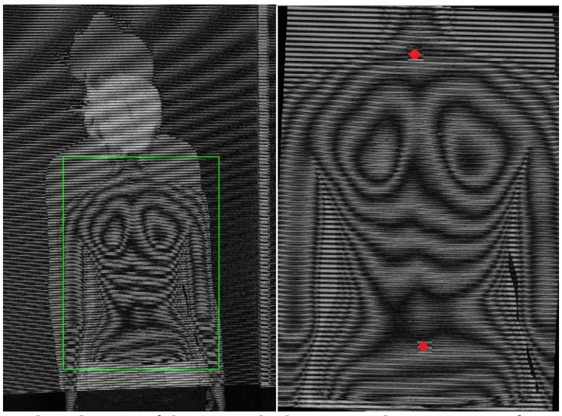


Fig. 5. The selection of that area which contains the necessary information (red dots – markers (vertebrae)

B. Image processing to filter out the required information

After selecting the necessary area of the image an auxiliary mesh had to be generated on it. This mesh will help to obtain points which will be the basis of the representation of 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 smaller the grid size is, the more accurate further calculations can be performed. The importance of the grid size will be shown in the next chapter.

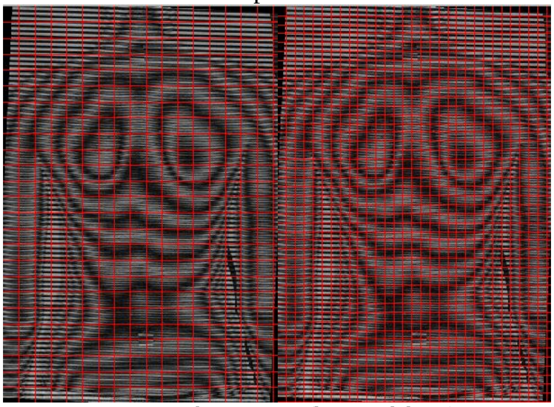


Fig. 6. Mesh generation (loose and dense)

The mesh created in the previous step was used for generating intersection points. These points were derived from the intersection point of a horizontal mesh line with the moiré fringes. The moiré picture and the created mesh had to be observed visually, looking for possible intersections. After this a mouse click had to be executed near it. The program checked the coordinates of the mouse click on the picture and selected the closest horizontal and vertical mesh line crossing point. That is the reason why the grid size is so important. When the grid size is large, the result can be inaccurate. Because of the small grid size the mesh will be denser, more horizontal and vertical line crossing points will appear which results a better approximation.

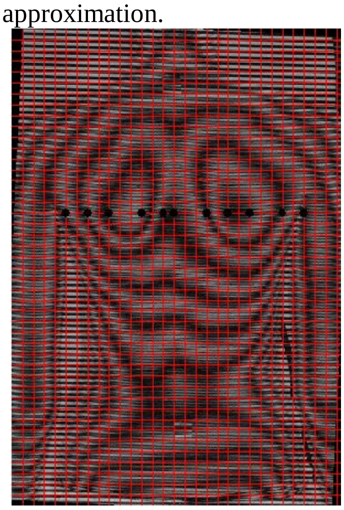


Fig. 7. Acquiring the intersection points on a horizontal mesh line

After generating the intersection points, these points need to be weighted. This weight describes which moiré fringe belongs to a point i.e. what kind of altitudinal information has the moiré fringe. The weighting was calculated by multiplying

the order of the moiré fringe with a constants (during the development this constant was 5). It was necessary for the fitting algorithm as a better fit can be performed if the points are not on the same horizontal line (if the ordinates of the points are not equal). Based on an agreement the innermost moiré fringe had the largest, the outermost had the least order. At the end of the acquisition of the intersection points the resulted weightings were added to the ordinates of the points.
The following picture and table describes this process.

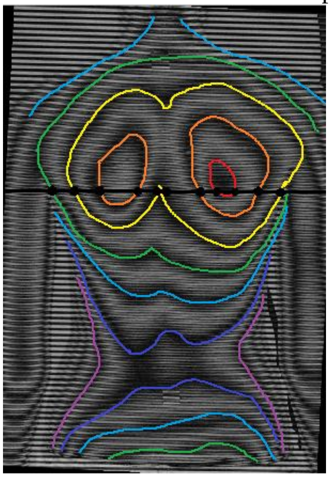


Fig. 8. Orders of the moiré fringes
(black line – the investigated horizontal line, black dots – the selected intersection points
purple line – 1st order, dark blue line – 2nd order, light blue line – 3rd order, green line – 4th order, yellow line – 5th order, orange line – 6th order, red line – 7th order)

For example the intersection points shown in Fig. 6. have the following orders and weights.

TABLE I. ORDERS AND WEIGHTS OF THE INTERSECTION POINTS

Point No.	*Ordinate (pixel)*	*Order*	*Weight (order x5)*	*Weighted ordinate*
1	425	4	20	445
2	425	5	25	450
3	425	6	30	455
4	425	6	30	455
5	425	5	25	450
6	425	5	25	450
7	425	6	30	455
8	425	7	35	460
9	425	7	35	460
10	425	6	30	455
11	425	5	25	450

In the next step an n^{th}-order polynomial curve was fitted to the weighted intersection points. In practice usually a maximum 5^{th}-order polynomial was used because of the general biological shape of the back mapped onto the transverse plane. The LabVIEW development system offers several built-in fitting processes. The general polynomial fitting method used during the whole development operated with Cholesky-algorithm. The more in-depth description of the fitting algorithm is beyond the scope of this paper.

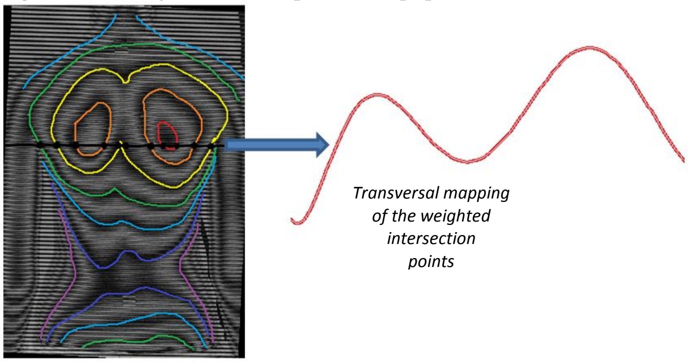


Fig. 9. The generation of the fitted polynomial to the weighted intersection points

A. Aquiring a point of the curvature of the spine

The main parts of this development were the determination methods of points of the spinal curve. To perform this, two methods have been implemented. The first one calculated the inflection points while the second one the extremes of the curve fitted during the previous step.
Executing one of these algorithms on every horizontal line result a set of points. A polynomial fitted to this set of points results the final shape of the spine, which is located on the surface perpendicular to the current image processing plane.
It should be noted that the detection process of the curve of the spine can be performed with only one point searching algorithm. Mixing of the methods is not practical as it can produce inaccurate results.

B. Extreme search algorithm

The first method was based on the extremes of the fitted polynomial. To locate extremes of a polynomial function, it needs to be differentiable two times. To find out the locations of the extremes, the first derivative of the curve had to be checked. If there was a solution to zero then there was an extreme at the resulted abscissa value. To obtain an extreme point correctly the ordinate value had to be calculated after substitution. That extreme was a point of the spinal curve, which was located in the valley of the back.

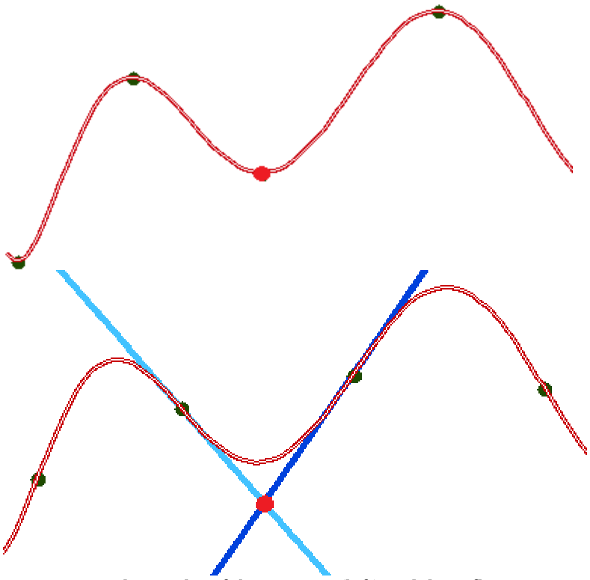


Fig. 10. The results of the extreme (left) and the inflexion point (right) searching
algorithm on the generated polynomial
(red line – the polynomial fitted in the previous step,
green dots – the resulted extreme or inflection points,
red dots – result of the algorithms, one point of the spinal curve)

Inflection point searching algorithm

The second method was based on the inflection points of the fitted polynomial. To locate the inflection points of a polynomial function, it needs to be differentiable two times. To find out the locations of the extremes the second derivative had to be checked. If there was a solution to zero, then there was an inflection at the resulted abscissa value. To obtain the inflection point correctly the ordinate value had to be calculated after substitution. In the next step those two inflection points had to be selected which were located at the valley of the back. In these points the algorithm created two tangential lines which lines intersects each other. This intersection point was a point of the curve of the spine.

C. *The determination of the curvature of the spine*

After executing the steps interpreted in the previous sections on every horizontal mesh line, a set of points were arisen. These points were the points of the spinal curve located on a surface perpendicular to the surface where the moiré picture processing was made.

To obtain the shape of the curve of the spine a fitting method had to be used again. Therefore, the algorithm operates here too with the built-in, general polynomial fitting method (like at the n^{th}-order polynomial fitting in *section* ***Hiba! A hivatkozási forrás nem található.***). It needs to be mentioned that due to the biological shape of the spine the order of the polynomial needs to be only 3^{rd} in this case.

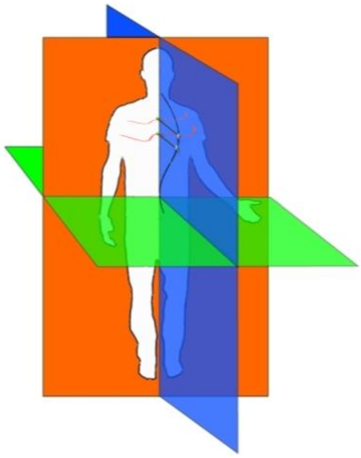
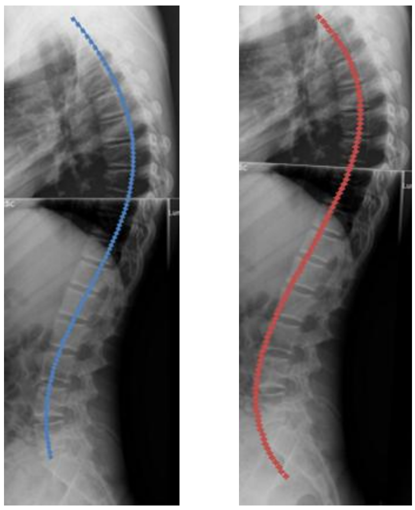


Fig. 11. Illustration of the mapping process during the curvature determination
(orange plane – frontal plane, blue plane – sagittal plane, green – transversal plane,
black curve – the detected curve of the spine,
orange and red curve – generated polynomial from the moiré fringes)

V. RESULTS

11 moiré pictures were chosen of patients with Scheuermann disease. Their moiré pictures were evaluated in two ways, we used the above described minimum-maximum method and also the inflexion method. After evaluation results were statistically compared.

Two spineline were generated according to the two showed method, than the lines were suited in the sagittal X-Ray pictures. For the best fitting LED light sources were used on two well touchable vertebrae, on the C7 and on the L5. These markers helped us to fit the generated spineline into the X-Ray picture of the original spine. Both spinelines approximate the original spine visibly well, but there are some differences in the statistical results.



a.) b.)

Fig.12. a.) Produced spineline using the inflexion point search algorithm b.) Spineline produced by us using the extreme search algorithm

After fitting the measured Cobb-angles were compared from the generated and from the original spineline. The original values derived from an orthopedist, our measurement based on the original definition of Cobb-angle where we used the borders of the vertebrae and the inflexion points of our line. By doing this we got 3 groups that were compared in pairs to the medical derived Cobb angle.

TABLE II. COBB-ANGLES ORIGINATED FROM THREE DIFFERENT WAYS

Patients No.	***Medical Cobb angles***	***Extreme searching method (Cobb angle)***	***Inflexion point searching method(Cobb angle)***
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

As it can be seen the medically generated Cobb-angles are in good agreement with the results from our two methods (to be considered the margin of error that is 5° using the original, medical method). With One Way Anova Analysis the mean difference between the extreme method and the medical method was 6,09°, in case of the inflexion point searching and the medical method the mean difference was 13,09°. In this way the extreme method seems to be more appropriate.
After this analysis we used Pearson correlations of comparing our two methods to the medical results. According to the graphs (see Figure 11 and Figure 12), the extreme method results showed better conformity to the medical Cobb-angles. In case of extreme method Pearson r is 0,9633, that is much better than the inflexion point searching method versus medical results (Pearson r is 0,7158).

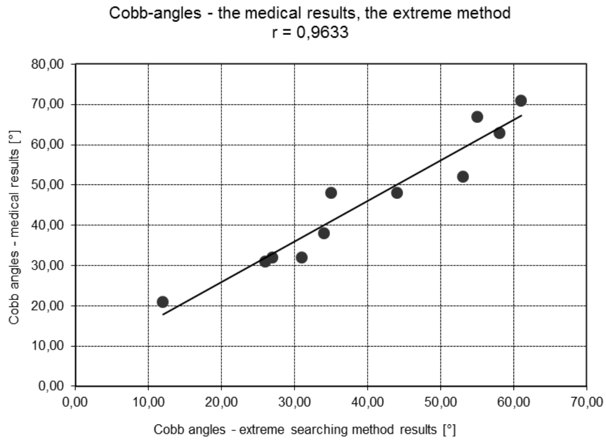


Fig. 13. Pearson correlation between the medical results and the extreme search method

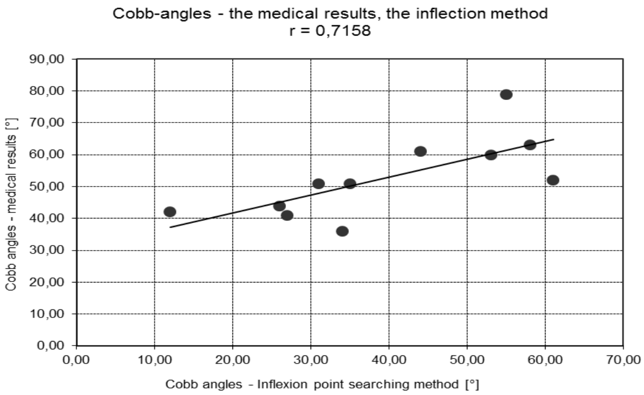


Fig. 14. Pearson correlation between the medical results and the inflexion point search method

For the statistical analysis we also used the paired t-test between the two methods and the medical Cobb-angles. These examinations showed similar results than the previous studies: compared the inflexion point search method to the medically generated Cobb-angles the p value using paired t-test was 0,0028. Compared the extreme search method to the medical results the p value was 0,0010. The examination did not show any significant differences in case of our methods according to the medical results, 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 searching method.

VI. CONCLUSIONS

Our research is up to date, because – as it is written above nearly 11% of children are concerned in this disease. Searching in the literature have not any modern research about Scheuermann disease, but there are a lot of different studies about screening and diangosing scoliosis. From the frontal plane taken moiré pictures the sagittal spineline can be produced using mathematical methods – written in this paper. In this way our method is useful for screening and diagnosing the Scheuermann disease. Its benefit opposite the X-Ray technique is that harmful radiation does not impair children's bodies. This examination can be repeated any number of times. Other advantage of this type of examination is – against the spinal mouse – the non-contact nature. Position of each points are fixed at the same time, so there is not any error because of children's movement. Both evaluating method used by us seem to be right, because there is not any significant difference between the Cobb angles from our methods and the medically derived results. The better solution is the extreme search method, it is proved also statistically. To verify our results it is important to evaluate more moiré pictures.

In order to increase the reliability and the image processing time of the moiré pictures, it is necessary for the software to have a higher degree of automation. During this kind of development the first task needs to be carried out is the automation of the transverse mapping step. In this operation the system need to the intersection point generation on all horizontal lines, the weighting of the points with the use of the orders and the polynomial fitting. The realization of this development can be eased by the Wavelet-transformation of the moiré fringes because with that mathematical method, the fringes could be transformed into a continuous contour line. As a consequence, the intersection point generation could be more accurate. In line with the moiré fringes a further idea presented itself. The weighting of the fringes could be more exact and accurate if the level difference of the fringes could be defined in some way. This requires further research.

The checking of the shape of the detected curve could be more efficient if the software would fit the 3rd order polynomial generated in the last step right to the X-Ray image and take more advantage of the markers.

The implementation of the Cobb degree calculation algorithm will be essential for the future because of the further research plans. After completing the before mentioned tasks the software could be extended to detect 3D deformations (vid. Scoliosis) and to create a full-scope diagnosis of the patient to equip the medical technology (especially in orthopaedics) with more artificial intelligence.

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