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Scoliosis testing features on the basis of electronically generated moire patterns

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Abstract
The Dept. of Mechatronics, Optics and Information Engineering, within the project team, had built an electronic moire equipment to visualize and diagnose scoliosis. The device generates a computerized moire phenomenon, which can be viewed and save for later examination. The applicability of the system was tested with statistical method from the moire patterns, which was created by the prototype device. The results of the calculations – to determine the rate of scoliosis by moire patterns – are promising and comparable with X-ray examinations.

Keywords: moire; scoliosis

1. Introduction

The Budapest University of Technology and Economics, Department of Mechatronics, Optics and Information Engineering as part of a team had won subvention on a tender of the National Office of Research and Technology to develop a new optical measuring family of orthopedical applications, to ensure more reproducible and more appropriate sampling and monitoring of orthopedic deformities (TECH 08-A1/2-2008-0121). The Salus-Orthopedtechnique Surgical Appliances Manufacture and Trade Ltd., The Department of Polimertechnique from Budapest University of Technology and Economics, The Orthopedic Clinic of the Semmelweis University, Varinex Informatics Ltd. and the Aga IT Ltd. are also the members of the winning consortium. The prototype of the moire measuring system, the target of the project, has been finished. The device's primarily purpose is screening and diagnostic, but it can be used for improve 3D modelling of orthopedic deformities and aid designing and controlling the manufacturing process of corrective tools.

The tasks of the project were the followings:
1. Calibration and error analysis of the prototype of the developed and installed moire equipment.
2. Test of the calibrated equipment, analysis of the possibility to determining the angular characteristic of idiopathic scoliosis from moire patterns on the basis of practical measurements.

2. Methods

A) The moire technique

The moire phenomenon is the result of the interaction between two periodic structures with different space frequencies. The measured or tested surface is similar to the contour lines of the maps but described in more general manner. Moire stripe is the manifestation of the moire phenomenon. These are generally the points of a surface with a given distance from the reference plane. Generally, moire surface is a set of points with a specific distance from a reference surface where distance is function of the fixed parameters of the layout. Moire stripes are the section lines of the measured and moire surfaces. The picture created via any capturing method, represents the section lines of moire and measured surfaces in two dimensions called moire pattern.

This optical method is one of the most modern ways for measuring the shape of the human body in space. The advantage is the simultaneity and touch-freeness, so the measured body is not charged with measuring pressure at all, information can be obtained all of its points at the same time. Its measurement applicability is wide[1–5]. This technique can also be used to measure deformation caused by pressure or by temperature change, when measurement with mechanical process cannot be carried out. It is also suitable to check dimensional accuracy of products made in production in series or in robotics[33,34,35].

B) Using Moire technique in orthopedics

The moire patterns' orthopedic – scoliosis testing – application is primarily used for screening by visual evaluation or diagnosing, as the back surface's asymmetry is very characteristically shows up[22]. The orthopedic applications are comprehensive, because the reproduction is simple but the result is very impressive and convincing[7,16–18]. In particular, it is used in combination with X-ray[19], but only making a moire pattern is not cause radiation pressure on the patient, which is a serious benefit of moire technique. The moire technique with computing, image processing and pattern recognition background is already a serious factor in this area[29–31].

The professional protocol on the physiotherapy of the structural idiopathic scoliosis prepared by the Professional College of Nursing and the Hungarian Society of Physiotherapists recommends moire topography beside diagnostic or imaging tests, bi-directional, stationary made X-ray image, the Cobb-angles (lateral size of curves), the rotation, the torsion, the sagittal profile view, the Risser sign, spiroergometric examination and the surface analysis.

3. The build device

The moire measuring equipment was designed and constructed in consultation with an orthopedical specialist to fit in the tender. The prototype of the device was tested in the Heim Pal Hospital, and in the Salus Orthopedtechnique Surgical Appliances Manufacture and Trade Ltd. In essence, that is a moire equipment with classic projection. The novelty is so far, that video projector used to project out the stripes to the reference and the test surface instead of a traditional projector. During the measurement, firstly a picture of the reference surface is taken, which is stored in computer memory or in mass storage. Then the test object takes the place of the reference surface, while the grating is projected with the same settings. The lattice is deforming on the examined surface depending on its shape. An other picture is taken from this, then the software prepare the moire pattern from the pictures of the reference surface and the test surface. The resulting moire pattern can be displayed or stored.

4. The examination and treatment of scoliosis

The idiopathic scoliosis's origin is unknown, the prevention of its formation is not yet known. However the disease can be recognized early with screening and it can be stopped and a significant and lasting improvement can be achieved with appropriate treatment.

A) The definition of the disease

By definition, the idiopathic scoliosis is the lateral curvature of the spine with structural changes, which forms without traceable reason before bone ageing. The structural changes of idiopathic scoliosis come about in all directions of space. The spine is curved, not only on the frontal plane, but also twists on the horizontal plane and become concave on the sagittal plane. The disease may begin in different ages and can appear in any part of the spine. The date of commencement of the disease is significantly affects the size of the curve. The earlier starting age of idiopathic scoliosis, the worse prognosis what patients can be expect. Thus, the lateral curvature of the spine is the scoliosis. The mobility of the vertebrae are often significantly reduced, so that the inward rectifying of the vertebra column is no longer possible. The lateral curvature of the spine is usually associated with the roll – torsion – of the vertebrae which results the so-called rib hump dorsal, and hump in the lumbar section.

B) The types of idiopathic scoliosis

The disease has two main groups, the functional and the structural scoliosis.

1. *Functional scoliosis:* The type of lateral curvature of the spine, which was not followed by torsion. The deformity can be corrected advanced state. It can develop without detectable reason which called primary functional scoliosis and also in the alternative, when some other reason lies in the background, such as lower limb length difference, muscle paralysis or herniated discs. Functional scoliosis is not three-dimensional change in the spine. Generally it can be well managed.

The therapy consists corrective physiotherapy maintenance. The primary treatment of functional scoliosis is to strengthen the back musculature. This type of functional scoliosis usually do not worsen and not transformed to structural scoliosis. The secondary functional scoliosis forming cause is one of the lower limb's real or apparent shortening. The half-pelvis on the shorter side is lower and because of the compensation of the inclined pelvis orientation, it become the convex lumbar scoliosis for the shortened side. It can be corrected with the limb length differential correction, for example with heel rise.

2. *Structural scoliosis:* It means the three-dimensional spine deformities, in clinical practice, the vast proportion of cases are in this group. The causes of scoliosis may be quite different, but it can develop without any known cause. Overall, the earlier year of life, the worse is the prognosis.

Characteristic of the deformity, is the so-called Cobb-angles *(Figure 1)*. This angle by definition is the exterior angle of the lines, perpendicular to the lines laying on the end plates of the beginning and ending vertebrae of scoliosis. 80–90% of structural scoliosis are idiopathic, 4:1 ratio girls are affected.

C) Consequences

Due to disease the motion of the vertebra column is greatly reduced and the chest is deformed. Beyond the aesthetic problems, sco-

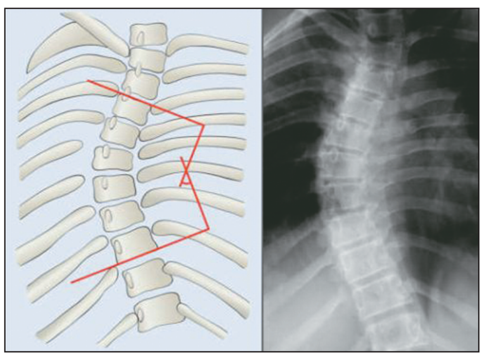

Figure 1. Definition of the Cobb-angle

liosis can lead to significant pain in the back, in very severe cases the consequences are heart and circulatory disorders. It should be noted that due to inappropriate static load the risk of herniated discs and other degenerative spine disorders increase as well.

D) Diagnosis

To determine the type of idiopathic scoliosis and curvature of the spine bi-directional X-ray is used, made of the total size of the standing patient's spine. The Cobb method is for determining the angle of curvature *(Figure 1)*. The prevalence around 10 Cobb-angles of idiopathic scoliosis is 2–3%. The bigger curves are significantly less frequent, incidence of curves above 30 Cobb-angles occur in 0.1–0.3%.

E) Treatment

The treatment of idiopathic scoliosis has essentially three options:

1. *Gymnastics:* Special gymnastics has developed to correct the scoliosis; the so-called Schroth therapy, which beside the active spinal stretching, strengthening the muscles asymmetrically in a corrected position, which is accompanied by a three-dimensional corrective breathing exercise. The regular long-term treatment occurs long lasting results.

2. *Corset:* Wearing corset become necessary, if the curative treatment is not sufficient in itself to correct the curvature. This is normally over 20 degrees considered.

3. *Surgery:* Above 50 degrees surgical approach is recommended.

5. Experiments

During the experiments an answer was sought – supported by measuring results – whether the determination of Cobb-angle with moire patterns – accepted by orthopedic specialists – is as accurate as the determination with X-ray pictures.

Well-known from the literature, that the rate of scoliosis is well characterized with a number which descript the figure of the spine shape. This defines the rate of disease severity, and also the possible treatment or intervention.

Three main techniques are known[25], Cobb, Ferguson and Tidestrom method In Hungary, the protocol uses the Cobb method, and rate is determined by X-rays.

Kamal[24] developed the algorithm to determinate Cobb-angles on the basis of the moire patterns.

A) The algorithm for determining the Cobb-angle

Using the the publication referred to[24] the figure the definition of Cobb-angle from moire stripes is the following *(Figure 2):*

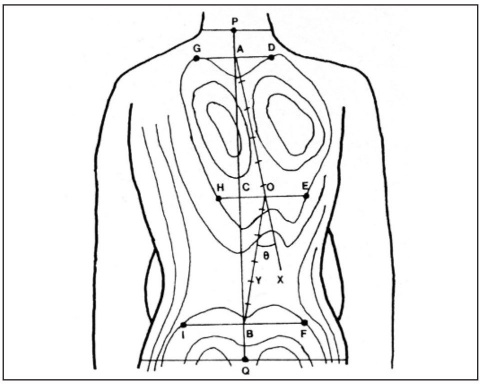

Figure 2. Algorithm for defining Cobb-angle[24]

On the basis of the *Figure 2,* angle is valid, that:

$$\Theta = < CAO + < CBO = Y1 + Y2 \quad (1)$$

To determine it, the line through the P and Q must be drawed, through the center of the neck and the waist. Then the moire curve on the scapulae, which shows the largest asymmetry must be found, and must be sectioned with a line perpendicular to PQ to get the H, C and E points. To the moire curve on which the H and E points lie tangent must be drawed from the top, resulting the G, A and D points. On the basis of the Figure 6 the I, B and F can be determined, and d1 , d2 and d3 values can be calculated.

$$d1 = 1/2(CH + CE) \quad (2)$$
$$d2 = 1/2(AD + AG) \quad (3)$$
$$d3 = 1/2(BF + BI) \quad (4)$$
$$\tan Y1 = |d1 - d2|/CA \quad (5)$$
$$\tan Y2 = |d1 - d3|/BC \quad (6)$$

eq. 5 and *eq. 6* must be substituted in *eq. 1,* then Cobb-angle can be calculated.

B) The conduction of the experiments

Two series of measurements were carried out, with the same person. The first series included seven recordings, and the body center of the subject stood with an average 400 mm in front of the reference surface. Between the recordings of each measurement, the subject took a short break, then went back to the measurement location. In between recording about one minute has passed. When the recordings was taken the subject was in a natural position, only held back the breath in the usual way, in the length of the exposure. The second series included seven recordings too, although the center line of the subject's body was located in the reference plane. The conditions otherwise were identical to the first series.

These two series of measurements was used to answer the following questions:

1. Cobb-angle, calculated by moire patterns of the same person, with the same independent circumstances (in a freely and loosely assumed position) add up fluctuation, which show the sensitiveness of the method to the subject's set.

2. From the values of Cobb-angles – calculated by pictures, which were taken in two different positions – the impact of the tested surface's position compared to reference surface was examined.

3. It can be seen from the descriptive algorithm of Cobb-angle that the set of E and H points contains a lot of subjective factors, and thus uncertainty, and therefore it was investigated, that within the same picture chosen the E and H points in different ways, how much uncertainty is caused with respect of the rate of Cobb-angle.

6. The measured data

Number	First series	Second series
	Cobb-angle [°]	Cobb-angle [°]
1	3.81	3.52
2	9.05	5.16
3	13.70	14.71
4	2.77	8.23
5	13.71	13.31
6	3.47	3.07
7	2.67	9.98
Average	7.02	8.00
Deviation	5.06	4.64

Table 1. The calculated values of Cobb-angle from the first and second recordings

As a first step the values on the basis of both series was submitted normality analysis with Kolmogorov–Smirnov's goodness to fit test[26]. The sample's empirical distribution's and a theoretical distribution function's fitting to each other was examined. The null hypothesis was, that the test sample and the theoretical distribution function does not differ in the significance level.

From the results, on the basis of the first and second series, the maximum value of test indexes *(Tables 2 and 3)* in both cases are less than the threshold (0.9D = 0.436), so there is no reason to reject null hypothesis, the data series of both samples can be considered as normal distribution on the confidence level (90%).

x_i	f_i	f_{ic}	$F_n(x_i)$	u_i	$F(u_i)$	D_i
2.00	2	2	0.29	–0.89	0.1841	0.1016
3.00	2	4	0.57	–0.70	0.2420	0.3294
4.00	0	4	0.57	–0.50	0.3085	0.2629
5.00	0	4	0.57	–0.30	0.3821	0.1893
6.00	0	4	0.57	–0.10	0.4602	0.1112
7.00	0	4	0.57	0.09	0.5398	0.0316
8.00	0	4	0.57	0.29	0.6179	–0.0465
9.00	1	5	0.71	0.49	0.6915	0.0228
10.00	0	5	0.71	0.69	0.7580	–0.0437
11.00	0	5	0.71	0.89	0.8159	–0.1016
12.00	0	5	0.71	1.08	0.8643	–0.1500
13.00	2	7	1	1.28	0.9032	0.0968

Table 2. The results of the normality analysis on the basis of first and second series (x_i – data, f_i – frequency, f_{ic} – sum of relative frequency, F – value of distribution function, d – value of test index)

x_i	f_i	f_{ic}	$F_n(x_i)$	u_i	$F(u_i)$	Di
3	2	2	0.285714	–0.86207	0.1841	0.1016
5	1	3	0.428571	–0.43103	0.3446	0.0840
7	1	4	0.571429	0	0.5000	0.0714
9	1	5	0.714286	0.431034	0.6664	0.0479
11	0	5	0.714286	0.862069	0.8051	–0.0908
13	2	7	1	1.293103	0.9015	0.1

Table 3. The results of the normality analysis on the basis of first and second series (x_i – data, f_i – frequency, f_{ic} – sum of relative frequency, F – value of distribution function, d – value of test index)

After the data series of both sample was considered as normal distribution on the confidence level, an answer was sought, whether the two samples in point of deviation and average can be considered part of the same population. In other words, the measured surface's and reference surface's distance from each other – in case of the tested dimensions – has no significant effect on the outcome. The comparison of the variances were performed with the Fischer–Snedecor's F test[27]. According to the null hypothesis, the two models – on the confidence level – are representative samples of normal distributions, which have same variance. In the course of the comparison of the two samples's variances, the test index was Femp = 1.1892, which is less than the critical.

So here was also no reason to throw away the null hypothesis, the two sample by variance on 90% significance level, can be considered as part of the same population.

To compare the averages, since the two samples is different – this case can be considered as a test with control group – two-sample t-test[28] were applied. By the null hypothesis, that two samples, on the confidence level, are the representative samples of normal distributions, which have same expected value. The two-sample t-test's empirical test index value is temp = 0.3776 which is smaller in this case too, than the critical value; t0.9crit = 1.782. So, according to the comparison of averages, there was also no reason to throw away the null hypothesis, that, the two samples, on 90% significance level, in point of averages can be considered part of the same population. It can be allocated, that on the significance level – the values of Cobb-angles calculated on basis of the recordings, which were made in the above mentioned circumstances – the subject's distance from the reference surface has no effect on the results, the system is not sensitive to this parameter.

To find out how the E and H point's settings impact the results, within the same record – which was made, when the examined surface was on the place of the reference surface – the E and H points were set in various places, as the algorithm described. From the resulting values of Cobb-angles, the average and deviation values can be calculated and conclusions can be drawn.

On the basis of *table 4.* it was found, that within one picture several times and independently intaked H and E points effected the deviation of the resultant Cobb-angle with lesser extent *(Table 4.)* than the total sample, but it had a significant effect, so the settings in the evaluation must be held carefully.

Number	Cobb-angle [°]
1	3.68
2	2.68
3	3.94
4	4.86
5	4.44
6	3.68
7	3.54
8	3.20
Average	3.751
Deviation	0.680

Table 4. The effect of the settings of E and H points on the uncertainty of Cobb-angles

7. Conclusions

According to the tests with the equipment, and control measurements the following statements can be made:

1. statement: The distance between the reference surface and the center of the subject's body – about 400 mm in the surroundings before the reference surface – has no significant effect to the rate of the Cobb-angle. Which was specified with the known algorithm and calculated from the moire patterns, which was made with the precalibrated, electronic moire equipment.

2. statement: The deviation – calculated from the Cobb-angle, which was specified from the moire patterns, was made with the moire equipment, from the subject, standing in the same position, without any particular body-setting algorithm – can be kept within five degrees.

3. statement: The deviation – calculated from the Cobb-angle, which was specified from the moire patterns, was made with the moire equipment – due to uncertainty of the settings of E and H points can be kept within 1 degree.

8. Comments and further research opportunities

In connection with the measurements, as well the further research, the following remarks can be made.

1. It would be worth to repeat the experiments with larger number of sample.

2. It would be worth to carry out the experiments with a person, whose scoliosis is diagnosed and more significant, medical history is known and who is not familiar with the system.

3. On the basis of the recordings, it would be worth to carrie out a complex examination, that the uncertainty of identification of certain points how much impact the resultant uncertainty, when determinate the Cobb-angle.

4. It would be worth that moire stripes – within moire patterns – will be subjected to a thinning image processing algorithm, to reduce the uncertainty of reading out datas.

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