IDENTIFICATION OF SPINAL DISORDERS THROUGH THREE-DIMENSIONAL RECONSTRUCTION OF THE HUMAN DORSUM

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Abstract: The most common human health issue among workers is pain in the dorsum region. This can be attributed to the occupational hazard inherent to certain activities that require great physical effort or incorrect posture. These workers may end up spending their entire working hours, after the aggressive behaviour to their spine, developing diseases and thus the pain in the dorsum that is the posterior area of the human body. In addition, most people do not focus on preventive behaviour, such as correct posture far from work that can cause spinal disorders over time, compromising the health of the spine. On the other hand, health professionals usually do not use technological tools to aid the postural analysis, performing only a subjective visual observation. Therefore, the identification of spinal disorders varies based on the degree of knowledge of each professional, yielding in misjudgement. With the advancement of technology, it was possible to develop an accessible system capable of mapping a 3D profile of the human dorsum, comparable to high-cost systems available on the market. This work aimed to validate a methodology of 3D reconstruction of human dorsa regarding the posture. The validation, approved by Ethical Committee, digitized 54 volunteers used a mathematical model based on geometrical optics (MMGeO). The digital surfaces were analysed by an expert who made the postural evaluation using the traditional Symmetrograph. There wasn't statistical difference between the methods when the disorder was clear, but MMGeO could identify small asymmetries while the traditional method fail to detect.

Keywords: Structured light, 3D reconstruction, Postural Analysis.

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INTRODUCTION

Lumbago is a pathology, also known as lower back pain, considered by the World Health Organization as a widespread functional health issue (WHO, 2023). It is estimated that 15 % to 20 % of adults experience back pain in any given year, and 50% to 80 % experienced at least one episode of lower back pain throughout their lives. Human body back is also named as dorsum, i.e. the posterior area of the body.

Incorrect posture is one of the main causes of lumbago, and posture can be defined as a position or attitude of the body in a static layout or the arrangement of the body parts in dynamic situations. Thus, the ideal posture transmits an aesthetically acceptable appearance, and it can be maintained for prolonged periods of time without causing discomfort or difficulties. In a situation of ideal postural alignment, the vertebral column presents normal curvatures and ideal alignment to sustain the body weight (PETERMANN; MEEIREIS, 2016).

The human posture is a complex system that varies individually (SALVE; BANKOFF, 2003). According to them, the causes for the postural disorders are many, and can be related to multiple diseases, as well as work habits. One example of thar work habits, can be linked to agricultural tasks, pointed out by Moreira et al. (2015). Spinal disorders related to bad postural habits causes aches and demand an investigation of the asymmetries in the lumbar region (OVERBERGH et al., 2020; STOKES; GARDNER-MORSE, 2016; NEIVA et al., 2018).

The traditional protocol to identify and to analyse postural asymmetries in the human dorsum is based on visual observation by experts (GOUVEIA et al., 2021). The asymmetries on the sagittal, frontal, and transverse planes of the human-being are, therefore, the areas of interest. The examination is subjective and can be aided by an instrument, named symmetrograph, that provides reference lines (vertical and horizontal) forming a grid divided by squares (GUIMARÃES; SACCO; JOÃO, 2007). The symmetry graph limits the analysis to high level disorders due to the errors of human subjectiveness (HILL et al., 2022). The symmetrograph is placed between the human-being analysed and the expert, where the grid formed by the lines orients the symmetry of the dorsum.

The visual observation, even using the symmetrograph, is feeble concerning small asymmetries, or irregular variations in the shape of the dorsum. The errors of observation and bigger variations of human evaluations demand a better protocol without the subjectivity of the traditional method. The use of the symmetrograph at the same time does not provide quantitative figures of the dorsum profile, offering only the idea of a relative level of asymmetry. In summary, the use of the symmetrograph is questioned as a Gold Standard technique to postural analysis, as we can see in the work of Iunes et al. (2009), when the results from the visual observation did not match with the outcomes made by the photogrammetry. As an alternative to the visual observation, the studies of spinal diseases are also done through radiography (single X-ray), despite the advances of the X-ray computed tomography (CT) and magnetic resonance imaging (MRI) (SANTIAGO et al., 2020). The analysis using a single X-ray and CT imaging techniques has some drawbacks, mainly concerning their radiation exposure (DAMILAKIS et al., 2010). Additionally, single X-ray, CT and MRI methods also present high costs regarding equipment, material and time-consuming of human experts, also demanding considerable area for civil and utility structure.

In order to avoid the cost and the radiation exposition, one can observe the need to develop radiation-free methods, such as the mathematical reconstruction of the spine based on topographic images (HUYSMANS et al., 2004); another example is the computer photogrammetry method proposed by Iunes et al. (2009). The effort in 3D scanning, in human application or not, can be seen easily in the literature, a one can address the work of Rocchini et al. (2001), who worked with structured light, or even the work of scanning the human face using coherent pattern projection (SCHAFFER et al., 2014). Regarding the effort linked to postural analysis, Petermann and Meeireis (2016) wrote a systematic review addressing at least 10 methodologies to deal with postural body, some using images, that aimed to overcome the absence of consensus about the best method to provide postural analysis.

Among the non-ionizing radiation, the structured light can be seen as an alternative for digitizing the dorsum, and it can also be changed by a laser line. A proposal to make a 3D reconstruction, using low-cost optics (projected light and webcam), associated with a mathematical model based on geometrical optics, was presented by Ribeiro et al. (2023) as a digitizing technique of objects, including the human dorsum. Optical profilometry stands out for not requiring physical contact with the objects being analysed, therefore, and it is indicated for experiments dealing with biological samples (COSTA et al., 2023). Barreto et al. (2019) employed a line laser and a digital camera to characterize soils with and without the presence of surface crust. The hypothesis behind the work was to prove that an interferometric method can be used in a feasible and accessible way to digitize the human dorsum, using profilometric maps to aid quantitative postural analysis linked to health issues that cause pain. Therefore, we validated a proposal of a setup using accessible equipment and a mathematical model proposed by Ribeiro et al. (2023) to provide profilometric maps of 54 volunteers, and compared with the traditional method, the symmetrograph.

MATERIAL AND METHODS

Volunteers

The validation of the proposed methodology using human beings was conducted after the approval of the Ethical Committee for Research using Human beings of the Federal University of Lavras. The 54 volunteers (28 males and 26 females) were all undergraduate and graduate students of the institution. All the volunteers were submitted to both tests (the optical test proposed and the Gold Standard test that adopts the Symmetrograph) and all the tests were carried out at the same appointment.

The proposed method was conducted by a specialist in optics and image processing, and the outcomes of the 3D images were analysed by the same expert that conducted the Symmetrograph test. In both cases, the volunteer was required to remove (his/her) shirt with (his/her) back (dorsum) turned to the projector and camera, as well as behind the grid of the symmetrograph.

Symmetrograph test

In 1, a picture of the expert (co-suthor) with a volunteer is shown, with the grid of the symmetrograph between them. The symmetrograph was made in a frame in aluminium of 2 x 1 m (height x width) with the grids formed by ribbon stripes. The size of the grid (cell) is 0.1 x 0.1 m. During the exam, the expert should stay at 2 m far from the symmetrograph while the volunteer at 0.3 m far from the symmetrograph.

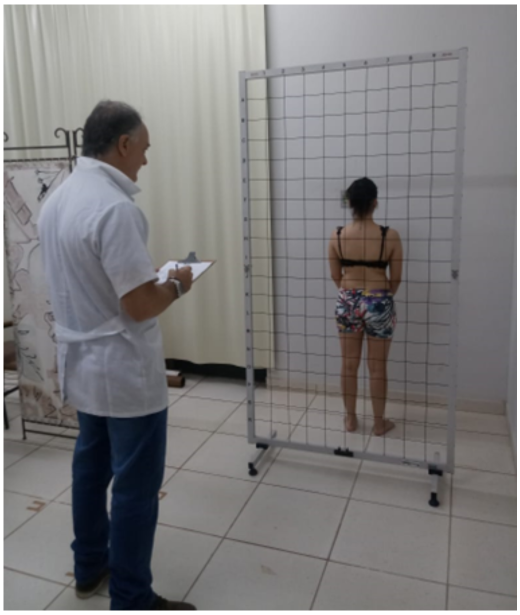

Figure 1: Symmetrograph representation with the expert and volunteer.

3D digital reconstruction of lumbar

The setup of the 3D reconstruction of the dorsum is presented in 2, the volunteer is illuminated by the lines projected and with those lines collected by a webcam. This method is named here as Mathematical Model based on Geometrical Optics (MMGeO) was presented in detail by Ribeiro et al. (2023).

The layout of the setup was based on mono-ocular vision (webcam) and the projection of structured light consisted of horizontal lines over the surfaces. Both, the webcam (HD, 3.0 Mb, USB, Logitech C270 960-000691) and the multimedia projector (Mx525b 3200 Lumens/Xga/Hdmi/3D Ready/Bndes) were

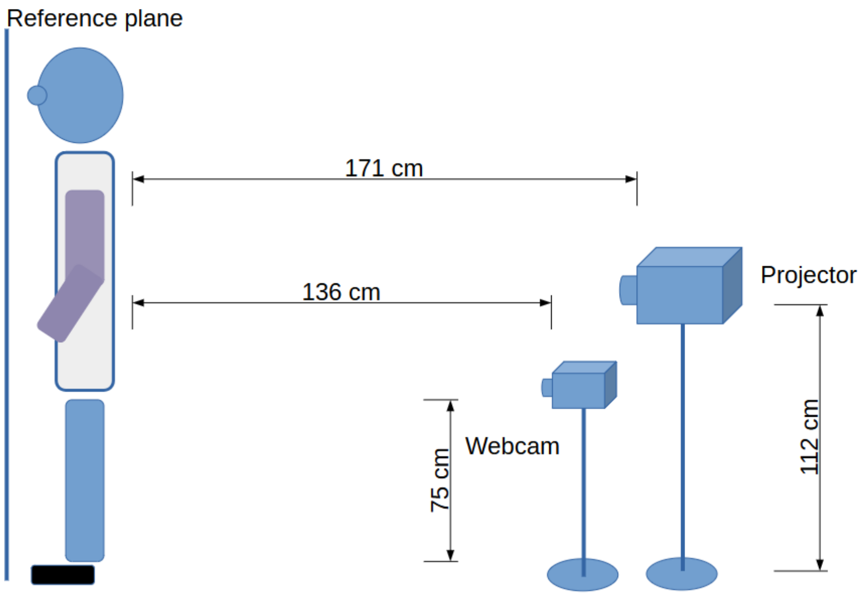

Figure 2: Experimental configuration with the webcam and the projector positioned in front of the object (dorsum of the volunteer).

connected to a computer that changed the position of the horizontal lines projected, thus, scanning all the dorsum, and mounted in just one image. A computer (Sony Vaio Core i3) was also used to process the profiles of the lines projected over the object. In 3, one can see the projection of lines upon the dorsum surface of a volunteer. The lines were also projected on a reference plane, without the volunteer.

The lines projected on the dorsum of the volunteers were coloured according to the RGB pattern (LUKAC; PLATANIOTIS, 2005) and associates the colours black and white, in such a way that one of the five projected colours could be best visualized in the captured images.

The thickness of each line was 1 (one) centimetre each, and an average of 20 lines were projected on the back of the volunteers. Each line was projected individually mounting a complete grid image after the scanning.

Statistical analysis

Contingencies tables and Fisher's Exact test were used to verify if the individual proportions classified in different categories were the same in the two populations, represented by the two tests: the MMGeO proposed and the Gold Standard test using symmetrograph (homogeneity test). They were compared in four situations: (1) Lateral view in Sagittal plane

Figure 3: Projection of RGB lines with black, white, red, green and blue lines upon the volunteer's thoracic-lumbar

by considering two categories (symmetric and asymmetric); (2) Lateral view in Sagittal plane by considering three categories (symmetric, hyper-lordosis and plane dorsum); (3) Frontal view of the dorsum by considering two categories (symmetric and asymmetric); (4) Frontal view of the dorsum by considering six categories (symmetric, scoliosis in "S", thoracic scoliosis at right, thoracic scoliosis at left, lumbar scoliosis at right and lumbar scoliosis at left). Where the thoracic region is pertaining of the region between the neck and the diaphragm, it is known as the higher spine area; and the lumbar region is the region pertaining the diaphragm and the sacrum, it is the lower spine area. The analyses were performed by using Fisher's test function of the R software (TEAM, 2020).

RESULTS AND DISCUSSION

The dorsum 3D reconstruction of the 54 volunteers was done in two steps: (I) regarding the graphical outcomes with the comments related to the challenges and characteristics, and (II) regarding the statistical comparison between MMGeO and the traditional method of symmetrograph.

In the MMGeO the red line projected presented the best performance in the digitization. The model constructed using the red line projected was able to distinguish the projection in white, brown and black skin, as well as it was not compromised by scars or tattoos. Therefore, in the case of human being as the object being digitized, the best choice would be the rede line projection.

Graphical outcomes and comments

The ability of the manipulation of the 3D image after the dorsum digitization allows the expert to better observe the surface with quantitative measurements. We summarize the whole digitization with two examples, addressing a normal spine and a spine with scoliosis.

In Figure 4a, one can see the cut of the dorsum in the Sagittal plane with the spine presenting its profile, and in Figure 4b, the 3D surface is presented with the expected normal spine with its profile over the measured one.

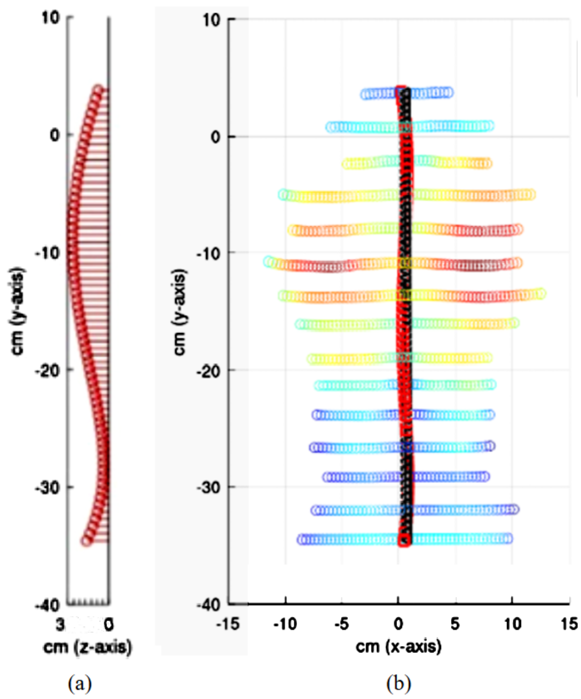

Figure 4: The 3D reconstruction of a normal dorsum using the MMGeO with (a) a cut of the 3D surface (sagittal plane), and (b) frontal view of the dorsum surface with the lines of the expected normal spine (black points) and the measured one (red points).

It is worth noting that the digital MMGeO could be manipulated quantitatively, with the possibility to trace lines and compare the results, i.e., in the lateral and in the front view of the dorsum. And in the case of the normal spine, the lines traced by the model presented the expected and the measured spine with the same profile.

However, besides the advantage of being able to manage the digital image, one can observe the sensitivity of the MMGeo, where in the case of Figure 5, a volunteer with Scoliosis could be noted by the expert using the MMGeO, but the spinal disorder was not noticed using the Symmetrograph by the same expert.

Statistical analysis comparing the two methods.

Lateral view results

The observed frequencies and percentages of the two categories (symmetric and asymmetric) considering the lateral view (Table 1).

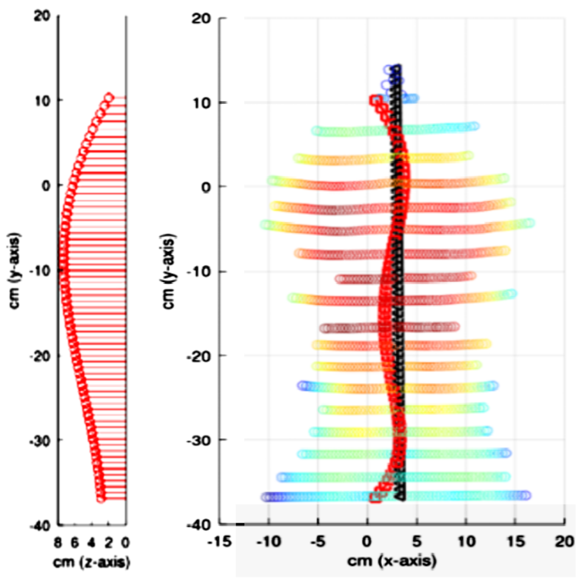

Figure 5: The 3D reconstruction of a volunteer with thoracic scoliosis on the right using the MMGeO where: (a) a cut of the 3D surface (Sagittal plane), and (b) the frontal view of the dorsum surface with the lines of the expected spine (black points) and the measured one (red points).

Table 1: Frequencies and percentages of the two categories (symmetric and asymmetric) using the MMGeO and the Symmetrograph.

Methods	Symmetric	Asymmetric
Symmetrograph	40 (74.07 %)	14 (25.93 %)
MMGeO	36 (66.67 %)	18 (33.33 %)

It can be observed in Table 1 that from the 54 volunteers, 40 were classified as symmetric and 14 as asymmetric by the expert using the Symmetrograph. When the proposed method (MMGeO) was used, it was obtained 36 volunteers as symmetric and 18 as asymmetric. In this case, the Fisher's Exact test was not significant (P>0.05), which indicates that the proportions of individuals in the two categories (symmetric and asymmetric) are not significantly different in both populations.

Therefore, both methods are comparable in classifying individuals in both conditions.

The observed frequencies and percentages of the three categories (symmetric, hyper-lordosis and plane dorsum) considering the lateral view are presented in Table 2. More details are presented about the asymmetric category in the last two columns of Table 2. In these columns, we have two types of asymmetries problems (hyper-lordosis and plane dorsum).

As shown in Table 2, out of 54 volunteers, 40 were classified as symmetric, 8 individuals with hyper-lordosis and plane dorsum, respectively (cases classified as asymmetric), by the expert using the symmetrograph. By using the MMGeO, the expert classified 36 volunteers as symmetric, 6 with hyper-lordosis and 12 with plane dorsum. In this case, the Fisher's Exact test was not significant (P>0.05) as well. Thus, the proportions of individuals in the three categories (symmetric, hyper-lordosis and plane dorsum) were not significantly different. Therefore, both methods were comparable to classify individuals in those three categories.

Table 2: Frequencies and percentages of the three categories symmetric, lumbar hyper-lordosis (Hyperlord) and plane dorsum (PlaneD) using the MMGeO and the Symmetrograph

Method	Symmetric	Hyperlord.	PlaneD
Symmetr	40 (74.08 %)	8 (14.81 %)	6 (11.11 %)
MMGeO	36 (66.67 %)	6 (11.11 %)	12 (22.22 %)

Frontal view results

The observed frequencies and percentages of the two categories (symmetric and asymmetric) by considering the frontal view are presented in Table 3.

As shown in the Table 3, out of 54 volunteers, 48 were classified as symmetric and 6 as asymmetric, by the expert using the symmetrograph. When the proposed method (MMGeO) was used, the expert classified the results obtained as: 38 volunteers as symmetric and 16 as asymmetric. In this case, the Fisher's Exact test was significantly different (P<0.05), which indicates that the proportions of individuals in the two categories (symmetric and asymmetric) are not the same in both populations. Therefore, the classification obtained by both methods are different.

Since differences were identified between the classification of both methods, the category asymmetric was subdivided into five categories i.e., Scoliosis in "S", Thoracic Scoliosis on the right, Thoracic Scoliosis on the left, Lumbar Scoliosis on the right, and Lumbar Scoliosis on

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Table 3: Frequencies and percentages of the two categories (symmetric and asymmetric) using the MMGeO and the Symmetrograph.

Methods	Symmetric	Asymmetric
Symmetrograph	48 (88.89 %)	6 (11.11 %)
MMGeO	38 (70.37 %)	16 (29.63 %)

the left. From Table 4 to Table 6 one can see the symmetric versus the asymmetric classifications. The observed frequencies and percentages of symmetric and Scoliosis in "S" considering the frontal view are presented in Table 4.

Table 4: Frequencies and percentages of the categories symmetric (Sym), Scoliosis in S (ScoS) analysed by both methods.

Method	Sym	ScoS
Symmetr	48 (88.90 %)	0 (0 %)
MMGeO	38 (70.37 %)	5 (9.26 %)

In Table 5 are presented the observed frequencies and percentages of symmetric and the asymmetric Thoracic Scoliosis on the right and Thoracic Scoliosis on the left considering the frontal view.

Table 5: Frequencies and percentages of the categories symmetric (Sym), Thoracic Scoliosis at right (TScoR) and Thoracic Scoliosis at left (TScoL) analysed by both methods.

Method	Sym	TScoR	TScoL
Symmetr	48 (88.90 %)	2 (3.70 %)	2 (3.70 %)
MMGeO	38 (70.37 %)	7 (12.96 %)	4 (7.41 %)

In Table 5 are presented the observed frequencies and percentages of symmetric and the asymmetric Lumbar Scoliosis on the right and Lumbar Scoliosis on the left considering the frontal view.

Table 6: Frequencies and percentages of the categories symmetric (Sym), Lumbar Scoliosis at right (LScoR, and Lumbar Scoliosis at left (LScoL) analysed by both methods.

Method	Sym	LScoR	LScoL
Symmetr	48 (88.90 %)	1 (1.85 %)	1 (1.85 %)
MMGeO	38 (70.37 %)	0 (0 %)	0 (0 %)

The Fisher's Exact test considering the frequencies presented in the Table 4 had significantly different values ($P<0.05$), which indicates that the proportions of individuals in the six categories (one symmetric and five asymmetric) are not the same in both populations. Therefore, the classification was different between the methods. Also, there are differences mainly between asymmetry types. After the comparison, the expert evaluated again the forms filled during the visual evaluation, and aided by the images of the digital process, concluded that other judgement could be done in a second round. We believe that the subjectivity of the Symmetrograph is the main reason for that. In the example presented before (Graphical outcomes), a low level of a Thoracic Scoliosis on the right was not identified by the expert when using the symmetrograph. The same expert was able to identify the disorder, with the aid of digital graphical manipulation of the frontal view made by MMGeO, even in a low level. It happened with other cases of Thoracic Scoliosis on the left and in "S", when the expert didn't have the sensitivity to judge properly the disorder at a low level, thus when the disorder is in its early stage, further trauma could be avoided preventing it from turning into a more serious health condition, that could reach an unreversible condition. All the results, lead us to a conclusion that reinforce the claiming pointed out by [11], that the known Gold Standard Symmetrograph must be questioned. At the same time the proposed MMGeO offers the free-radiation characteristics present in X-ray and Computerized Tomography. The flexibility and the objectivity of the proposed method could facilitate a precise diagnosis using an accessible setup. In addition, the mathematical model allows the automation of the analysis using Artificial Intelligence.

CONCLUSIONS

The use of the Mathematical Model based on Geometrical Optics (MMGeO) presented the same results of the visual observation aided by the Symmetrograph. However, the MMGeO was able to identify low level of disorders that were discarded by the visual observation, showing that the MMGeO can be an alternative to the Symmetrograph method and its subjectivity due to human judgement.

The accessibility, the flexibility and the objectivity of the proposed method could aid the early identification of the spine disorders by using a low-cost setup and allowing its automation and the use of Artificial Intelligence.

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