SYSTEM FOR POSTURAL ANALYSIS BASED ON DIGITAL IMAGE PROCESSING AND 3D RECONSTRUCTION

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Abstract: Accurate but simple assessment of human posture is a requirement of many physiotherapists. However, a system to carry out this task is not available yet. The main problem in conventional methods of postural analysis is that each physiotherapist has to use his (her) subjectivity to identify the deviations, through observational-based methods [1, 2]. There is not an applicable tool to detect and to quantify the deviations, and the progress of the treatment can not be precisely assessed and followed. Thus, the purpose of this study is to design and to implement a computational system to assist physiotherapists in the postural analysis of their patients. The quantification of the posture deviations and 3D reconstruction techniques are some of the explored topics in this paper. A description of the implemented methodology and software is also provided.

Introduction

Posture is essentially the position of the body in space. Optimal posture is the state of muscular and skeletal balance that protects the supporting structures of the body against injury or progressive deformity, whether in movement or at rest [3, 4]. Correct posture involves the positioning of the body to provide minimum stress in joints. Conversely, bad posture increases stress in joints, so damage and changes to the surrounding tissues may occur [3, 4].

Posture also involves the chain-link concept of body mechanics in which problems anywhere along the body can lead to problems above or below that point [5, 6, 7]. For example, knee pain can arise from pelvic joint disorders. The effects of a bad posture can be far reaching involving respiratory, digestive, and circulatory systems as well as the muscular and skeletal systems [5, 6].

Currently, the observation-based method for postural analysis is the most used by physiotherapists. Plumb lines, inclinometers, and grids (or posture charts) are used to assist the estimation of the deviation from ideally erect posture. The quality of this analysis depends on the subjectivity of each physiotherapist, who classifies the deviations in "small", "medium" or "large". The use of these qualitative adjectives (instead of numbers) results in an inaccurate analysis, what is just one of the problems.

Some physiotherapists have already improved the usual method by taking pictures of their patients. In this case, the main issue is that there is not a reliable tool to measure the pictures. Moreover, it is difficult to organise the files along a timeline, in order to provide ideal comparisons between two or more stages of the treatment.

Looking for solutions for these problems, some products were brought to market with the promise to improve the postural analysis method. Generally, these softwares are based on databases and measurement features that solve part of the problem. Other questions such as costs and processing speed discourage the users to utilize these systems. Moreover, in most cases they are just partially useful due to high complexity, and until now there is not an applicable tool that incorporates the features that physiotherapists really need.

After several interviews with specialists in postural analysis, it has been found that the method could be improved in some aspects, such as precision and data storage. Moreover, the use of 3D resources in postural analysis is strongly desirable, in order to explore the *biofeedback* benefits. The use of this technique can bring better treatment results than conventional methods [8].

The purpose of this work is to build an innovative solution for the physiotherapists regarding postural analysis. The software is being developed based on C++ language and OpenGL standard for 3D graphics. Main features are: measures over pictures, 3D model generation, file management facilities, and stress analysis in joints.

Materials and Methods

A. The assembly scheme

The picture acquisition system is based on a digital camera, a tripod and adhesive labels to be used as markers on the floor and background. As the goal is to develop a commercial product, the methodology of picture acquisition has been created by using only one digital camera, to minimize costs. Basically, the camera and tripod positions should not vary, while the patient stays in upright position for pictures of his anterior, posterior, left and right sagittal views. Adjustments of heights and distances have to be done and the room should have a good light condition to ensure the well working of the image processing algorithms.

The first step of the assembly scheme is to mark some points by using the labels in the background plane. The distances from the floor are: 0, 50, 75, 100, 125, 150, 200, and 250cm. These marks should be carefully fixed in a vertical line, in order to be used as references in the pictures.

The second step is to calibrate the tripod distances and heights. Three levels are enough to fit all patients' heights preserving the accuracy of the method. The first distance level should be marked when by looking through the camera lens it is possible to see all the markers (0 to 250cm), and the markers 0 and 250 are located close to the edges (bottom and top) of the visual field. Similarly, the second level should be marked when the visual field includes points 0 to 200cm, and the third when it contains points 0 to 150cm. For each calibrated distance, the tripod height has to be adjusted in a manner that the camera points straight to the markers 125, 100 and 75cm respectively, trough an horizontal line. Figure 1 illustrates the assembly scheme.

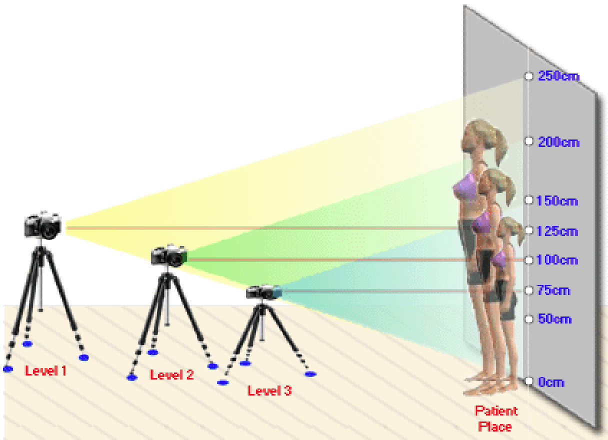

Figure 1: The Assembly Scheme to Carry Out the Hardware Calibration.

Therefore, patients with heights more than 200cm should be analyzed at level 1. To patients with heights between 150 and 200cm the tripod should be moved to the second level, and for the patients with heights less than 150cm, the first level is recommended.

B. Calibration of the "u" unit

In the observational method of postural analysis used by the physiotherapists, the asymmetry detection is not made over the real measurements in patients' body. Instead, it is made over a projection of these measurements. Figure 2 shows the use of a grid, that exemplifies this technique and Figure 3 illustrates the difference between the real size and its projection.

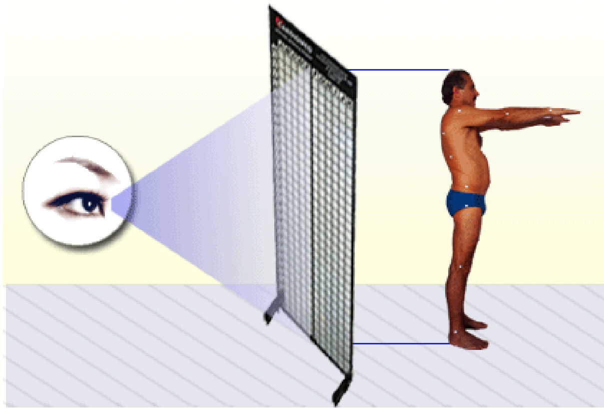

Figure 2: The Use of Grids in Postural Analysis.

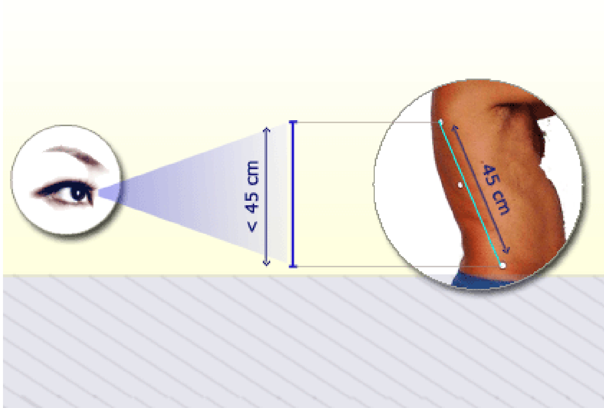

Figure 3: The Difference between the Real Size and its Projection.

It should be a mistake if the measurements made by the software were dimensioned in *mm* or *cm*, because in the new proposed method the measurements are made over a two-dimensional plan (on the pictures).Then, it has been created a new unit to be used in the system that quantifies the distances between two points on the pictures in a straight line: the unit *u*.

In order to calibrate this unit, an association tool between the real scale and the picture scale is provided. The last step of the system setup is to associate 50cm on the background plane to 50*u* in the software. For the level 1 the association must be between 50*u* and the distance between points 100 and 150. For the level 2, the points 75 and 125 should be used in the same mode, and to calibrate the scale in the third level, the points 50 and 100 are the references.

The coordinate system origin takes up the same place of the label 0 fixed on the background plane, and should be inserted by the user through the *origin* tool. This feature permits the physiotherapist to compare the heights and the horizontal symmetry between markers in the patient's body.

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C. Image processing

After the assembly stage, the software is ready for use. Pictures of the patients must be taken in anterior, posterior, left and right sagittal views to be inserted in the system. White adhesive labels are used to contrast specific points in patient's body, being fixed in a strategic manner on shoulders, elbows, pelvis, knees, ankles, and other body parts. The objective is to detect these points by using image processing algorithms on the acquired pictures.

The software can read several image types (JPG, GIF, BMP, PNG, TIFF, and PCX), what ensures flexibility regarding camera models. The images are copied to a safe directory automatically, when read by the software. Furthermore, they are associated to the patient's file in the database.

The first stage of image processing is the descriptors extraction. The software provides tools to calculate the mean and standard deviation of pixel energy, using the pixels that belong to one of the labels. The size of the chosen label is also taken by the same tool. That is, the user may use the *zoom* tool, select one of the labels in the picture, and execute the *calibration* tool.

The automatic detection of the other labels begins with the search for pixels, in the whole picture, that are between the energy interval $Mean \pm 3SD$. The areas containing these pixels are binarized using Otsu algorithm, which chooses a threshold to minimize the intraclass variance of the black and white pixels [9]. Next, a set of image processing techniques is used to find objects according to the performed calibration. Some techniques are described below.

- *Binarization*: computes a global threshold (level) using Otsu algorithm [9] and convert an intensity image to a binary image based on this threshold.
- *Connectivity*: Connects and labels the pixels of the same object in a binary image.
- *Sub-area processing*: Selects a part of the image to perform some other operation on it, avoiding unnecessary delay. Only areas that contain potential objects are processed.
- *Area*: It weights different pixel patterns unequally when computing the area. This weighting compensates for the distortion that is inherent in representing a continuous image with discrete pixels. For example, a diagonal line of 50 pixels is longer than a horizontal line of 50 pixels. As a result of the weighting that the implemented function uses, the horizontal line has area of 50, but the diagonal line has area of 62.5.
- *Compacity (CC)*: Measures the similarity between an object and an ellipse using its perimeter and area (see equation 1). Compacity factor is invariant to translations, rotations and scale changes [10].

$$CC = \frac{perimeter^2}{4\pi \cdot area} \qquad (1)$$

- *Dilate*: Dilates the object by using a circle ($\phi = 3\,pixels$) as structuring element object.
- *Erode*: Erodes the object by using the same circle as structuring element. *Dilate* followed by *Erode* results in *Closing* operation, and *Erode* followed by *Dilate* results in *Opening* operation [10].

The image processing has been made on the blue channel of RGB colors. This channel has been chosen due to providing a high contrast between the skin color and the white labels.

D. Software features

In order to provide a dynamic posture analysis by using the pictures, it was created a toolbox with some resources. As the automatic image processing may cause some mistakes detecting erroneous points, the system provides the possibility to add and delete points from the pictures manually. Each point added to the picture is also added to a window with its coordinate (x, y) given in *u*. The *zoom* tool allows the physiotherapist to zoom in the picture and to add points right on the desired spot. Measurements between two points can also be done by the system, using the *u* unit. Each measure appears next to a line (see Figure 4), and more details such as line dimension and the inclination between the line and the horizontal and vertical axes can be found in the *Lines* window (see Figure 5a).

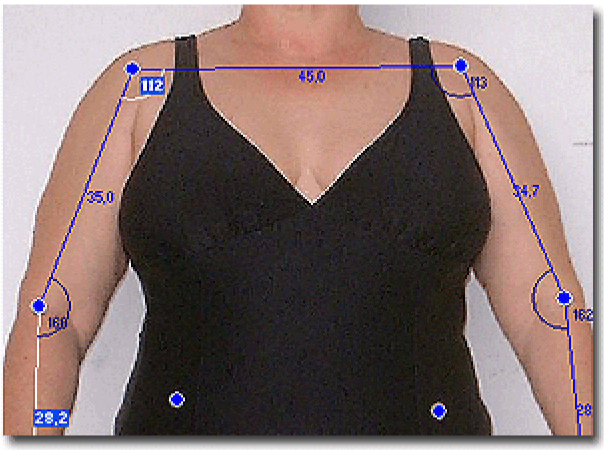

Figure 4: Points, Lines and Angles Shown Over the Pictures.

Similarly, angles (in degrees) can also be measured between two lines. They are drawn on the pictures (see Figure 4) and more details can be found in the *Angles* window as shown in Figure 5b.

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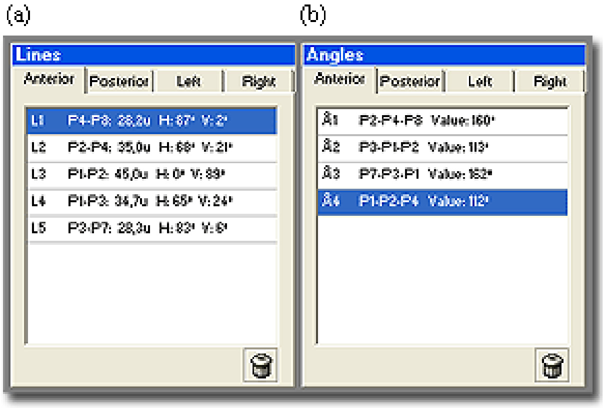

Figure 5: (a) Lines Window with the Line Size and its Inclination. (b) Angles Window.

The software stores all these data in a database, so that it is possible to associate more than one analysis to a patient. This feature allows the physiotherapist to compare different stages of the treatment.

E. 3D models

The main objective of the body 3D model construction is to provide an easy way of showing the postural analysis results. The OpenGL API is used for object renderization, interpreting the data obtained in the analysis and creating a perspective image of the patient's skeleton.

Basically, the idea consists in a tree-dimensional matrix of points. These points are linked building triangles, that makes the objects surface (see Figure 6). The OpenGL allows these objects to be rotated, translated, and resized in execution time, what enables the adjustment of the model to fit its body segments in accordance to the measurements on the patients.

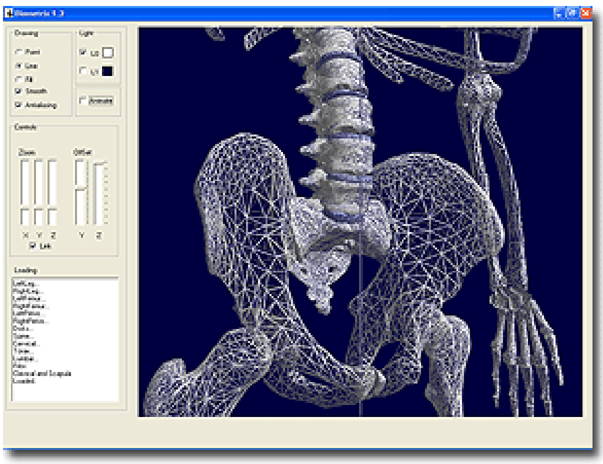

Figure 6: Surface Made of Triangles.

By using a 3D specialized software, a human skeleton model with the main bones of the body has been constructed. This model is resized and shown by the system at each analysis (see Figure 7). The 3D coordinates are created from the combination of 2D coordinates (from anterior, posterior, and sagittal pictures) obtained previously by the system.

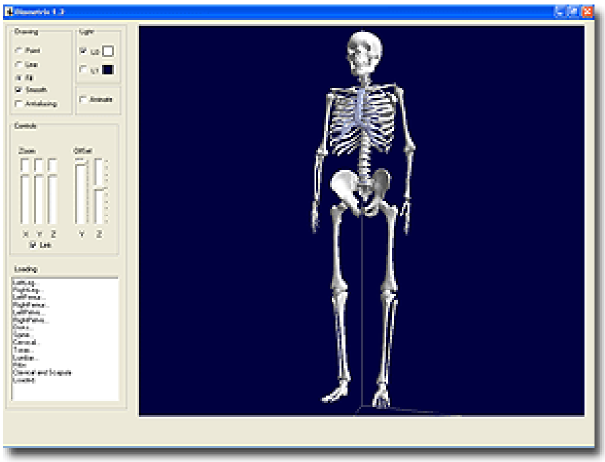

Figure 7: The 3D Model Rebuilt by the Software.

The generated tree-dimensional model has substantial visualization resources, such as zoom, rotation, and shadow/light effects.

Results

In order to ensure the proper working of the system, the assembly instructions for the pictures acquisition equipment has to be strictly followed. The automatic label detection algorithm has been satisfactory, with more than 90% of the labels correctly detected in pictures taken with considerable resolution and good light condition.

The system does not need high resolution pictures to work well. However, the higher the resolution, more precision is obtained, but more processing time is needed. Tables 1 and 2 show some computational overhead test results with some different picture size.

Table 1: Performance Test Results to the Image Processing Algorithm Using a PC with a PIII 1GHz Processor and 256Mb RAM.

PC specifications: PIII 1GHz processor, 256Mb RAM				
PICTURE	800x600	1024x768	1800x1200	2048x1536
TIME (s)	0.94	1.24	3.07	4.47
FOUND LABELS	7/12	9/12	12/12	12/12

Table 2: Performance Test Results to the Image Processing Algorithm Using a PC with a PIV 2.4GHz Processor and 512Mb RAM.

PC specifications: PIV 2.4GHz processor, 512Mb RAM				
PICTURE	800x600	1024x768	1800x1200	2048x1536
TIME (s)	0.33	0.67	1.26	1.75
FOUND LABELS	7/12	9/12	12/12	12/12

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The interface implementation is almost finished. The acquisition of three-dimensional coordinates through bi-dimensional points has to be still simplified. This is essential to ensure easiness to the users in generating 3D patients' models.

The software has separated windows for each provided resource: Pictures, Points, Lines, Angles, and Toolbox. They can be moved on screen in execution time, at any moment by the user. This type of interface is usually found in commercial softwares of great acceptation in the market. Figure 8 shows the developed interface for the postural analysis system.

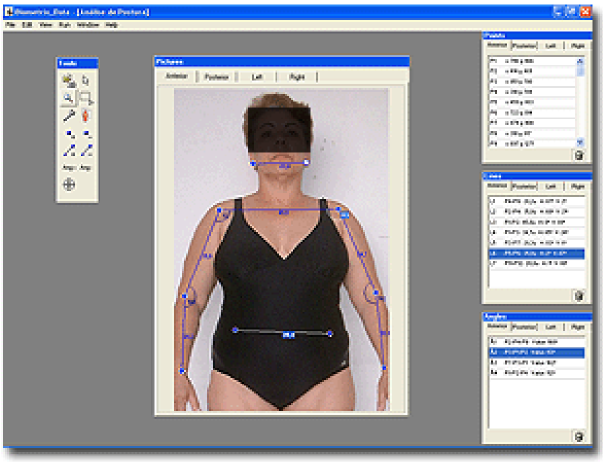

Figure 8: Software Interface Based on Separated Windows for Each Resource.

Discussion

Through interviews with physiotherapists and RPG (Global Posture Reeducation) professionals, it was found that few technological resources have been used in the field. It happens due to the high complexity and associated costs of the developed applications. In general, the physiotherapists need an "easy use" tool to support the treatment tasks, what is not available yet.

The current version of the system has been created with this feature, and eliminates the subjectivity problem in quantization of postural deviations found in patients' body. We believe that with the 3D resources incorporated, a complete tool will become available providing the *biofeedback* benefits to the patients.

Observing that the calibrated tripod distances may vary in accordance with the camera model, it has not been made a study to standardize them. Even being minimal variations, it is highly recommended to follow the assembly instructions in order to find the appropriate distances for the tripod.

Conclusions

From these preliminary results it has been concluded that even minimal deviations of spinal alignment and trunk rotation as well as leg and arm positions can be detected by the system. The software also organizes the patients' files providing precise comparisons between the previous and the actual analysis, so that the progress along the treatment can be quantified.

We believe that the main problem of conventional postural analysis is solved by the use of the proposed software. The automatic quantization of the deviations trough the *u* unit avoids physiotherapist doubts, when sizing the deviations.

The 3D models add flexibility and simple visualization of the deviations. Currently, the implemented methodology is working satisfactorily, but not as easy as desired by a common user. The next step is to integrate this feature to the software.

Another future step is to apply the method in physiotherapy and RPG clinics, as a study to discover what are the most common postural deviations found in population nowadays. We expect also to verify whether the use of a computing system can improve the patients' motivation in following the physiotherapist orientations, though interviews with the patients.

The method for biomechanical analysis of static posture is still under development. It is based on validated human models of mass distribution, and the patient weight. Through the detected points, and the mass of each body part, it's possible to estimate stress in joints such as knees and ankles, pointing out pain causes.

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