Static and Dynamic Body Analysis in Physiotherapy and Rehabilitation

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***Abstract*— World Health Organization estimates that 80% of the world population is affected of back pain during his life. In this work, we propose a novel tool for posture and range of movement estimation based on the analysis of 3D information from depth maps. The system purpose is the posture reeducation to prevent musculoskeletal disorders, such as back pain, as well as tracking the patients evolution in rehabilitation treatments.**

I. Introduction

The body posture evaluation of a subject manifests his level of physic-anatomical health given the behavior of bone structures, and especially of the dorsal spine. For instance, common musculoskeletal disorders (MSDs) such as scoliosis, kyphosis, lordosis, arthropathy, or spinal pain show some of their symptoms through body posture. There already exist systems to measure body posture (stereo vision techniques [2] with multiple cameras or accelerometers), but they used to be expensive, invasive and inaccurate.

In this work, we present a novel semi-automatic noninvasive system that uses the information provided by RGB-Depth cameras to elaborate a clinical postural analysis through the examination of anthropometric values. Given a set of keypoints defined by the user, RGB and depth data are aligned, depth surface is reconstructed, and accurate measurements about posture, spinal curvature, and range of movement are computed. The system is accurate and reliable to be include in the clinical routine.

II. Posture analysis system

We designed a full functional system devoted to help in the posture reeducation task with the aim of preventing and correcting musculoskeletal disorders. The system is composed by three main functionalities: a) static posture (SP), b) spine curvature (SC), and c) range of movement analyses (RM). First, RGB and Depth data are aligned using the geometric model provided by the Kinect software, and a pre-processing step to remove noise and reconstruct surfaces based on computing mean depth values and resampling algorithm [4] is performed.

A. Static posture analysis (SPA)

This module computes and associates a set of three-dimensional angles and distances to keypoints manually defined by the user (and saved as a protocol). Figure 1 shows an example of a predefined protocol (the set of manual annotated keypoints together with the list of distance and angle relations to be computed).

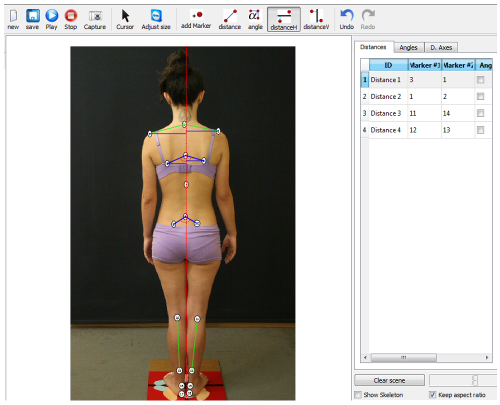

Fig. 1. Static posture analysis example.

In order to obtain an intelligent and automatic estimation of posture measurements, we define a correspondence procedure among manually labeled keypoints and protocol markers. We formulate markers matching as an optimization problem. Suppose a protocol analysis (template) T composed by N markers, $T = \{T_1, T_2, ..., T_N\}$, $T_i = (x_i, y_i, z_i)$, and the current analysis C composed by the same number of markers, $C = \{C_1, C_2, ..., C_N\}$ (predefined template and current set of keypoints defined by the user, respectively). Our goal is to make a one-to-one correspondence so that we minimize the sum of least square distances among assignments as follows:

$$\text{argmin}_{C'} \sum_{i=1}^{N} \|C'_i - T_i\|^2 \,, \tag{1}$$

where C' is evaluated as each of the possible permutations of the elements of C. For this task, first, we perform a soft pre-alignment between C and T using Iterative Closest Point (ICP), and then, we propose a sub-optimal approximation to the least-squares minimization problem. ICP is based on the application of rigid transformations (translation and rotation) in order to align both sequences C and T. This attempts to minimize the error of alignment $E(.)$ between the two marker sequences as $E(\mathcal{R}, \mathcal{T}) = \sum_{i=1}^{N} \sum_{j=1}^{N} w_{i,j} \|T_i - \mathcal{R}(C_j) - \mathcal{T}\|^2$, being $\mathcal{R}$ and $\mathcal{T}$ the rotation matrix and translation vector, respectively. $w_{i,j}$ is assigned 1 if the i-th point of T described the same point in space as the j-th point of C. Otherwise $w_{i,j} = 0$. Two things have to be calculated: First, the corresponding points, and second, the transformation ($\mathcal{R}$,

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$\mathcal{T}$) that minimizes $E(\mathcal{R}, \mathcal{T})$ on the base of the corresponding points. For this task, we apply Singular Value decomposition (SVD). At the end of the optimization, the new projection of the elements of C is considered for final correspondence. Then, Eq. 1 is approximated as follows: Given the symmetric matrix of distances M of size $N \times N$ which codifies the set of $N \cdot (N-1)/2$ possible distances among all assignments between the elements of C and T, we set a distance threshold θ_M to define the adjacency matrix A:

$$A(i,j) = \begin{cases} 1 & \text{if} \quad M(i,j) < \theta_M \\ 0, & \text{otherwise} \end{cases} . \tag{2}$$

Then, instead of looking for the set of $N!$ possible assignments of elements of C and T that minimizes Eq. 1, only the possible assignments (C_i, T_j) that satisfies $A(i,j) = 1$ are considered, dramatically reducing the complexity of the correspondence procedure.

B. Spine curvature analysis (SCA)

The objective of this task is to evaluate sagittal spine curvatures (curves of the spine projected on the sagittal plane) by noninvasive graphic estimations in kyphosis and lordosis patients. The methodology proposed by Leroux et al [1] offers a three-dimensional analysis valid for clinical examinations. The therapist places the markers on the spine. Only few markers are selected and the 3D curve that represents the spine is reconstructed by linear interpolation (Figure2(b)). Then, we can obtain anthropometric kyphosis and lordosis measurements. The capacity analysis of the spine is reinforced by a three-dimensional environment for a thorough examination by the therapist (Figure2(c)). An example of spine interaction (placing markers) and computation (interpolation) are shown in Figure 2(a).

C. Range of movement analysis (RMA)

In order to complement the posture analysis procedure, we compute the range of movement of different body articulations. For this purpose, we perform user detection using the Random Forest approach with depth features of Shotton et al [3] and compute the skeletal model. The physician then selects joint articulations and automatically obtains their maximum opening and minimum closing values measured during a certain period of time (Figure 2(d)).

III. Results

The video data uses a 8 bits VGA resolution at 30Hz, and we capture frames at 640×480 pixels, like the infrared camera. Regarding the implementation we used the Kinect SDK, PCL, VTK, and Nokia Qt. A battery of 500 simple tests has been labeled by three different observers, with an inter observer correlation superior to 99% for all planes (X, Y, Z). A total of 20 subjects participated in the validation of the method.

Results for different distance of the device to the scene are shown in TableI. AAV and '$\circ$' correspond to the average absolute value and degree, respectively. The obtained results validate the accuracy of SPA and RMA modules in millimeters and degrees, respectively. In addition, in order to validate the SCA, the Leroux protocol [1] was applied to 10 different subjects. The relationship between lateral radiographic and anthropometric measures was assessed with the mean difference. It has used Cobb technique on the lateral radiograph in order to obtain the coefficients of kyphosis and lordosis. The results of the SP validation are shown in Table II. Moreover, specialists in physiotherapy agreed the results are accurate enough for assisted diagnosis.

TABLE I

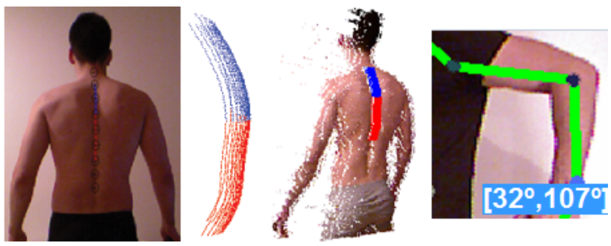
Pose and range of movement precision

Distance subject-device (m)	1,3	1,9	2,2
AAV ($\circ$ movement)	2,2	3,8	5,2
AAV (mm)	0,98	1,42	2,1
AAV ($\circ$ angles)	0,51	1,04	1,24
AAV (%)	0,46	0,77	1,3
Standard Error (%)	1,01	1,18	1,71

TABLE II

Validation of spinal analysis

	Khyposis range	Lordosis range
AAV ($\circ$)	5	6



(a) (b) (c) (d)

Fig. 2. (a) Markers placed to perform an analysis. (b) Automatically reconstructed 3D spinal cloud. (c) Three-dimensional examination environment. (d) Skeletal model and example of selected articulation with computed dynamic range of movement.

IV. Conclusion

We presented a system for semi-automatic posture analysis and range of movement estimation using depth maps. The aim of the system is to assist in the posture reeducation task to prevent and treat musculoskeletal disorders. Given a set of keypoints defined by the user, RGB and depth data are aligned, depth surface is reconstructed, and accurate measurements about posture, spinal curvature, and range of movement are obtained.

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