Flexible Feedback System for Posture Monitoring and Correction

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***Abstract*—In this paper, we propose a framework for guiding patients and/or users in how to correct their posture in real-time without requiring a physical or a direct intervention of a therapist or a sports specialist. In order to support posture monitoring and correction, this paper presents a flexible system that continuously evaluates postural defects of the user. In case deviations from a correct posture are identified, then feedback information is provided in order to guide the user to converge to an appropriate and stable body condition. The core of the proposed approach is the analysis of the motion required for aligning body-parts with respect to postural constraints and pre-specified template skeleton poses. Experimental results in two scenarios (sitting and weight lifting) show the potential of the proposed framework.**

***Index Terms*—Posture monitoring, feedback, skeleton**

I. INTRODUCTION

Posture assessment is important in health [1]–[3], sports [4] and in many work related tasks [5], [6]. Maintaining a correct posture throughout the day avoids injuries [7], and improves not only the physical condition but also self-esteem [8]. Posture analysis is usually performed by specialized therapists in health care centers [9] or specific sports facilities, which usually involves high costs either for the patient and/or the insurance companies. Additionally, the analysis is performed at a moderate number of appointments throughout the year, and only the measurements of these appointments can be used for assessing the posture across time.

In order to support posture analysis, human tracking systems using RGB-D sensors (e.g. Kinect) are being investigated and deployed for health-care and sports [10]–[12]. They can support the therapists for performing accurate physical measurements, and allow continuous visualization of posture metrics while performing specific exercises. In this paper, we want to go one step further, and not only evaluate posture metrics (e.g. [10]–[12]), but also provide real-time feedback to patients and/or users in how to correct their posture automatically without requiring direct intervention of a therapist.

The proposed approach is inspired by the physical assistance system of [13]. In [13], the authors presented an algorithm that assesses the quality of the movement being performed by the user, and also provides feedback for guiding the user in improving the movement. Feedback proposals are computed by comparing the movement with a template skeleton pose or action, without specifying pose constraints of joint configurations. These feedback instructions are presented visually and through human interpretable messages. In this paper, we adapt [13] for specifically performing posture monitoring and correction. We study how to measure postural defects using a skeleton acquired with a depth sensor, and how to use these measurements for guiding the user in converging to a healthier and better posture. Two particular scenarios are analyzed: the first consists in examining the body posture while sitting on a chair, which is one of the main causes of health related issues in work environments [14], [15]. The second is related to sports and incorrect exercising in gyms, e.g. weight lifting [16], [17], which causes many significant injuries. The specific scenario consists in analyzing the body posture while lifting a bar.

In summary, the contributions of the paper are the following: 1) Identification of the main body features of a correct posture (straight back and symmetric limbs), and an evaluation technique using skeleton poses acquired from depth sensors; 2) New metrics for continuous evaluation of postural defects; 3) Real-time feedback for assisting patients and users in correcting and maintaining a correct posture.

This paper is organized as follows: Section II provides a brief introduction of the feedback system proposed in [13]. Section III presents the proposed approach for measuring the quality of the posture, the angle between the back and the gravity vector, and symmetry of the body limbs about the plane of symmetry. Experimental results are presented in Section IV, and Section V concludes the paper.

II. BACKGROUND

This section concerns the background material that is used throughout the paper. It is inspired and based on the physical assistance algorithm proposed by Antunes et al. [13]. We will briefly review the motion representation and the feedback proposals of [13], which will be appropriately modified for analyzing postural defects in this paper.

A. Motion Representation

We represent a skeleton instance with N joints by $\mathsf{S} = [\mathbf{j}_1, \ldots, \mathbf{j}_n, \ldots, \mathbf{j}_N]$, where each joint is given by its 3D coordinates $\mathbf{j} = [j_x, j_y, j_z]^\mathsf{T}$. An action is defined as a skeleton sequence $\mathsf{M} = \{\mathsf{S}_1, \ldots, \mathsf{S}_f, \ldots, \mathsf{S}_F\}$, where F is the number of frames of the sequence. In order to appropriately compare different skeleton instances, the skeletons are spatially registered such that the world coordinate system is placed at the hip center, and the projection of the vector from the left hip to the right hip onto the x-y plan is parallel to the x-axis. For achieving invariance to different limb lengths, the skeletons S are normalized such that the body part lengths match a reference skeleton. In order to handle rate variations of different subjects performing similar actions and mitigate temporal misalignments, Dynamic Time Warping (DTW) [18] is employed.

B. Feedback Proposals

In order to provide feedback to users for physical assistance, the authors of [13] propose a motion feedback system. Skeleton poses S are represented by a discrete number of body-parts $\mathsf{b} \in \mathcal{B}$, where each body-part b is composed by specific joints. Given a template skeleton pose $\hat{\mathsf{S}}$, the proposed algorithm computes a rotation for each body-part b of S that best aligns it with the corresponding body-part $\hat{\mathsf{b}}$ of $\hat{\mathsf{S}}$. Then, the body-part b and rotation with the highest 3D error are selected for computing feedback proposals. As discussed in [13], the feedback proposals are presented as feedback vectors and messages to the user.

III. PROPOSED APPROACH

A. Definition of Correct Posture

As discussed in [7], posture is defined as the relative body joint dispositions at a given time, where every joint has an effect on the other joints. A correct posture is defined as a position in which minimum stress is applied to each joint. There are many features that define a correct posture, refer to [7] for a thorough analysis. In this paper, we tackle two of them due to the fact that they can be analyzed using an affordable depth sensor (e.g. Kinect) and also because they are simple to explain to the user. The first is related to having a straight back that is aligned with the gravity vector. The second is the balance between left and right limbs. The objective is that both legs and both arms should exercise the same force. This can be observed if the joints of arms and legs are symmetric with respect to a plane that intersects a straight line, called line of gravity in [7], and which divides the human body into two identical parts. Figure 1 illustrates the representation of a symmetric human body with respect to the plane of symmetry.

B. Metrics for Measuring Correct Posture

In contrast to the general feedback assistance system proposed in [13], we propose three measurements for evaluating postural defects. As shown in Figure 2, a skeleton S is divided into 5 body-parts, namely the back, the left and right arms, and the left and right legs. These body-parts were chosen because they can be used, as discussed in the next sections, to analyze general postural features discussed in the previous section in a simplified manner.

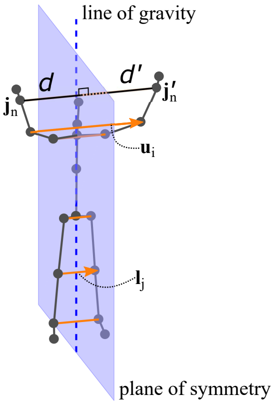


Fig. 1. For a correct posture, the body joints of the limbs should be symmetric about the plane of symmetry that intersects the line of gravity [7]. The purple plane represents the plane of symmetry, which divides the skeleton into two parts. One part contains the left limbs (arm and leg, $\mathsf{b}_l^{(\uparrow,\downarrow)}$) and the other contains the right limbs (arm and leg, $\mathsf{b}_r^{(\uparrow,\downarrow)}$). The orange arrows connect corresponding joints on different parts, e.g. the right elbow $\mathbf{j}_n$ is connected with the left elbow $\mathbf{j}'_n$. The vectors $\mathbf{u}_i$ and $\mathbf{l}_j$ identify the direction of the lines connecting corresponding joints.

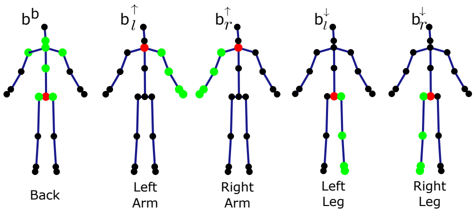


Fig. 2. The human body is divided into 5 parts. The set of joints for each body part is highlighted in green and its local origin is the red colored joint. The notation of each body-parts is shown above the respective skeleton.

1) Angle between Back and Gravity Vector: The objective of the first feature of correct posture is to have a straight back that is aligned with the gravity vector. Considering this, we propose to define the spine vector $\mathbf{w}$ as the vector that connects the hip joint, which is also the origin of the world coordinate system, with the neck joint. Since the skeletons are previously aligned so that the z-axis is aligned with the gravity vector, analyzing the deviation from a correct back posture is achieved by computing the angle θ between $\mathbf{w}$ and the direction $\mathbf{z}$ of the z-axis:

$$\theta = \angle(\mathbf{w}, \mathbf{z}). \tag{1}$$

The higher the angle θ, the worse is the back posture. The upper-part of the body (the first three body-parts, back, left and right arms) can be corrected by using the rotation $-\theta$ about the x-axis. Figure 3 shows the angle θ needed to rotate the upper part of the skeleton S such that it is aligned with the gravity vector.

2) Symmetry Between Upper and Lower Limbs: The second feature of a correct posture concerns the symmetry of the upper and lower limbs of the human body with respect to the plane of symmetry (refer to Figure 1). The plane of symmetry is defined as the plane that intersects the line of gravity and is aligned with the y-axis. As discussed in Section II-A, since the skeleton is pre-normalized such that the world coordinate system is placed at the hip center, and rotated such that the projection of the vector from the left hip to the right hip onto

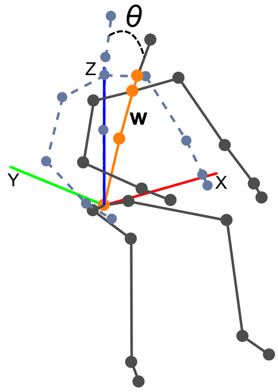


Fig. 3. Angle θ between the spine vector $\mathbf{w}$ (orange color) and the gravity vector (blue color represents the z-axis).

the x-y plane is parallel to the x-axis, the plane of symmetry correctly separates the left limbs ($\mathrm{b}_l^{(\uparrow,\downarrow)}$ in Figure 2) from the right limbs ($\mathrm{b}_r^{(\uparrow,\downarrow)}$ in Figure 2).

In order to achieve symmetry between the upper and lower body, the orthogonal distance between the joint $\mathbf{j}_n$ and the corresponding opposite joint $\mathbf{j}'_n$ with respect to the plane of symmetry should be equal. Let us define the distance d_n as the orthogonal distance between joint $\mathbf{j}_n$ and the plane of symmetry, and the same for the distance d'_n associated with joint $\mathbf{j}'_n$. Symmetry about the plane of symmetry is verified if $d = d'$, and, since the skeletons are normalized and centered with respect to the hip center, this is verified in case $\mathbf{j}'_n = [-j_{n_x}, j_{n_y}, j_{n_z}]$. Two corresponding body-parts $\mathrm{b}_l^{(\uparrow,\downarrow)}$ and $\mathrm{b}_r^{(\uparrow,\downarrow)}$ are symmetric if their joints are all symmetric about the plane of symmetry.

In order to simplify the analysis and visualization of the symmetry of joints about the plane of symmetry, we will also measure the angles of the lines connecting corresponding joints, which will be called critical angles. Referring to Figure 4, let us define the vectors $\mathbf{u}_i$ and $\mathbf{l}_j$, with $i, j = 1, 2, 3$, as the vectors representing the directions of the lines that connect corresponding joints on different sides of the plane of symmetry. The vectors $\mathbf{u}_i$ concern the upper part of the body, $(i = 1)$ represents the shoulders, $(i = 2)$ the elbows $(i = 2)$ and $(i = 3)$ the wrists. Regarding the lower part of the body, $\mathbf{l}_j$ with $(j = 1)$ connects the hips , $(j = 2)$ the knees and $(j = 3)$ the ankles. Considering this, six critical angles are defined:

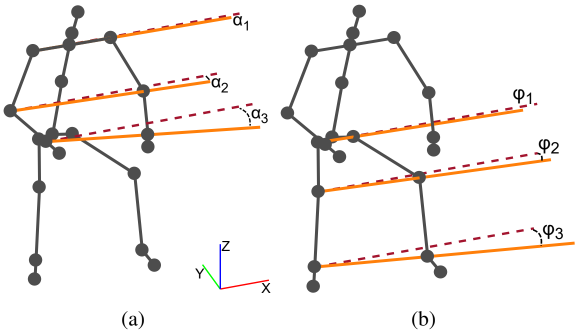
$$\alpha_i = \angle(\mathbf{u}_i, \mathbf{x}) \quad \text{with} \quad i = 1, 2, 3, \tag{2}$$

$$\varphi_j = \angle(\mathbf{l}_j, \mathbf{x}) \quad \text{with} \quad j = 1, 2, 3, \tag{3}$$

where, $\mathbf{x}$ is the direction of the x-axis. Figure 4 depicts the critical angles. The values of the critical angles for a correct posture should be as low as possible, ideally zero.

C. Posture Correction System

We explained in the previous sections how to compute and measure postural indicators, this is, the angle between the back and the gravity vector, and the distances and critical angles between corresponding joints. This section explains how this information is used for assisting users in correcting their posture and converging to a more adequate physical state. The output of the proposed system is feedback suggestions, visual information and messages, in how to correct the back and have a symmetric body posture.



(a) (b)

Fig. 4. Representation of the critical angles between the lines connecting opposite joints (solid orange lines) and the lines parallel to the x-axis (red dashed lines).

As depicted in Figure 5, the input to the system is a skeleton pose S of the user, which is acquired using the Kinect in this paper. The proposed algorithm is sensor independent and other technologies from which a skeleton can be estimated can also be used. The first step is to align and normalize S, as explained in Section II-A. Then, the angle θ between the skeleton back and the gravity vector is computed. This information is used as a first feedback indicator (feedback message 1 in Figure 5) and also used to correct virtually the current skeleton, obtaining S_c, for the next processing stages.

Given the corrected skeleton S_c obtained using a back rotation proportional to the angle θ, the next stage consists in identifying which lower and upper limbs of S_c should be moved so that the user's skeleton pose is symmetric about the plane of symmetry (refer to Figure 1). In order to achieve this, a database of correct skeleton poses for relevant postures and exercises is acquired using the supervision of an expert. For static postures like sitting, a discrete set of poses is sufficient, while for dynamic movements like lifting, a skeleton pose sequence is acquired. The corrected skeleton S_c is matched with one of the poses in the database (for dynamic movements, DTW is employed, as suggested in Section II-A). Then, the skeleton analysis system proposed in [13] is used to identify the lower $\mathrm{b}^{(\downarrow)}$ and the upper $\mathrm{b}^{(\uparrow)}$ limbs that have the highest 3D error with respect to the template pose (highlighted in green in Figure 5). For an appropriate posture, these limbs should be a symmetric version of their counterparts about the plane of symmetry.

Let us define the operator s which reflects a body-part b about the plane of symmetry:

$$s(\mathrm{b}) = \tilde{\mathrm{b}}, \text{ with } \tilde{\mathbf{j}} = [-j_x, j_y, j_z]^{\mathsf{T}} \; \forall \, \tilde{\mathbf{j}} \in \tilde{\mathrm{b}}, \tag{4}$$

where $\tilde{\mathbf{j}}$ is a general joint in $\tilde{\mathrm{b}}$. Consider that the limb parts that had highest 3D error were $\mathrm{b}_l^{(\downarrow)}$ and $\mathrm{b}_l^{(\uparrow)}$ for the lower and upper parts, respectively (the same works for the right limbs). Ideally, these body-parts should match the symmetric version of $\mathrm{b}_r^{(\downarrow)}$ and $b_r^{(\uparrow)}$, respectively, about the plane of symmetry. In order to guide the user to converge to a correct symmetrical posture, we compute the ideal symmetric versions:

$$\begin{aligned} \tilde{\mathsf{b}}_r^{(\downarrow)} &= s(\mathsf{b}_r^{(\downarrow)}) \\ \tilde{\mathsf{b}}_r^{(\uparrow)} &= s(\mathsf{b}_r^{(\uparrow)}). \end{aligned} \tag{5}$$

Finally, feedback proposals are obtained by computing the rotation matrices [13] that best align $\mathsf{b}_l^{(\downarrow)}$ with $\tilde{\mathsf{b}}_r^{(\downarrow)}$ and $\mathsf{b}_l^{(\uparrow)}$ with $\tilde{\mathsf{b}}_r^{(\uparrow)}$, respectively. From these matrices, feedback proposals are suggested to the user (feedback messages 2 and 3 in Figure 5).

IV. EXPERIMENTAL RESULTS

In this section, we evaluate the proposed posture assistance system using two different datasets, **sitting** and **lifting**, acquired using the Kinect v2 sensor.

A. *Sitting*

This dataset, acquired using the the Kinect v2 sensor, consists in different people sitting on a chair while writing or using a laptop. Generally, people tend to realize different body postures over time, many of which can cause serious physical injuries in the long-term. Usually, subjects start by having a correct posture, with a straight back aligned with the back of the chair and a symmetric posture of the upper limbs. As time goes by, the subjects start to feel tired of being in the same position and move the shoulders asymmetrically and bend the back towards the table. Having such an incorrect posture for a long period of time can cause serious injuries to the spine.

We tested our system using this dataset in order to assess if it could provide useful alerts to the user and support him in having a correct posture across time. In case the back angle or the critical angles are above a certain threshold, an alert is triggered and feedback proposals are spoken to the user by the system. Figure 6 shows an example where the feedback is proposed with the objective of correcting the back posture.

The objective is to study the posture of the subject while sitting on a chair during the working time. Considering this, we recorded a subject while sitting during 8 consecutive hours (regular working day time) with and without feedback proposals. The goal is to analyze the posture of the subject measuring the critical angles (refer to Sections III-B1 and III-B2). Figure 7 shows the box plot over the critical angles with respect to a template correct posture for both experiments. Note that, in these experiments we do not evaluate the angles regarding the lower limbs of the subject due to the fact that while sitting, the lower limbs are not seen by the camera. Throughout the day, the subject has multiple postures while sitting due to the fatigue, these posture variations can be seen in Figure 7(a) where θ is the most affected angle. This angle θ concerns the angle of the back with respect to the line of gravity, concluding that the back of the subject is the most problematic body-part for this specific analysis. For the same experiment, we employed the feedback system to advise the subject and propose posture correction when predefined thresholds are reached. Figure 7(b) illustrates the critical angles for this experiment. Observing Figure 7, we conclude that the subject tends to correct his posture by following feedback proposals when an alert is provided, decreasing the values of the critical angles, specially the angle between the back and the line of gravity (θ).

B. *Lifting*

The objective of this experience is to analyze if the system is able to support and help a user in correctly lifting a weight. Most people incorrectly lift a weight by bending and executing most of the force using their back. Also, they tend to lose balance when lifting the weight upwards, which causes an asymmetric body-posture and serious injuries. The ideal way of lifting a weight is to lower the upper body using a straight back and lifting the weight by exercising most of the force using the leg muscles.

The **lifting** dataset consists in multiple users lifting a metallic bar located on the floor, raise it over the head and then place it again on the floor. The experiment was performed by 100 different subjects following the same conditions (the same movement and the same bar). Figure 8(a) illustrates two examples (top rows) of the lifting exercise, the green skeleton sequence represents a correct posture for lifting and the red sequence represents a incorrect posture for lifting. Figure 8(b) depicts the back angle θ across time while lifting the bar, where θ_1 identifies a correct posture (top row), and θ_2 concerns the incorrect posture (second row). It is visible that θ_2 has a sudden increase when the user starts to bend to pick up the bar and also when leaving it on the floor. The reason of these high values of θ is that the user does not use the legs to apply the force to accomplish the lifting movement. Instead, the user bends the back to lift the bar and this is not the recommended posture to follow, causing severe injuries to the spine.

Each subject was asked to raise the bar two times. In the first, no instructions were provided. In the second, our systems displays feedback alerts and messages on a screen in front of the user. Figure 9(a) shows a box plot over the angles for the first attempt (no feedback), and the angles for the second attempt are shown in Figure 9(b). It is remarkable that, apart from the angle θ, the critical angles also had a significant decrease when compared with the first attempt. Resulting that, the user tends to correct the symmetry of the body following the feedback messages when applying force to lift the bar. Remark that with the proposed postural assessment and correction system, the user constantly has a more correct and healthier body posture, even for subjects without any experience in correct weight lifting.

V. CONCLUSIONS

In this paper, we propose a system to guide users in how to correct their posture by providing real-time feedback without requiring a direct intervention of a therapist or a sports specialist. This is achieved by continuous monitoring of postural defects and using a database of correct skeleton poses for relevant postures and exercises acquired using the

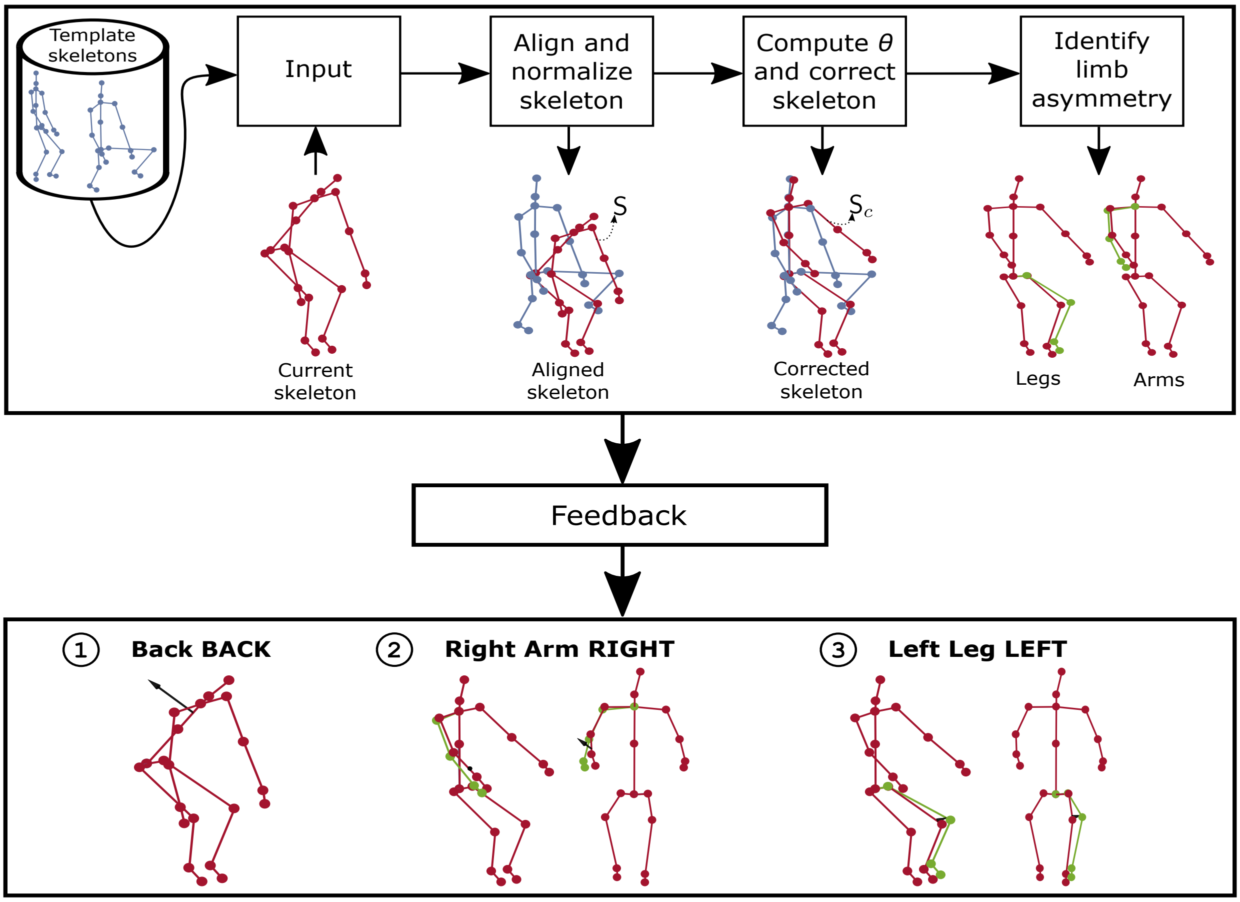


Fig. 5. Overview of the different stages of the proposed approach. A database of template skeleton poses $\hat{S}$ (blue) is acquired using experts in the field relevant for the posture analysis application. The red skeleton S represents the current pose to which posture correction feedback should be provided. First, the skeletons are aligned and normalized and the angle for the back correction is computed. The corrected skeleton S_c is then generated by applying a rotation proportional to the angle for the back correction. Then, the lower and upper limbs to be moved are identified (green). Finally, feedback with information about the motion required to adjust the back, and the lower and upper limbs for converging to a correct posture is provided. The feedback is supplied in the form of visual information (black color arrows) and human interpretable messages. Better visualized in color.

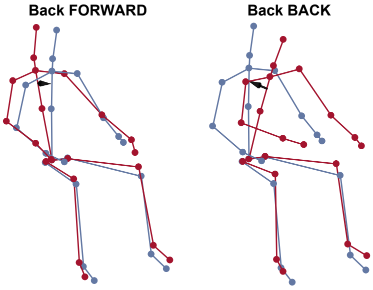


Fig. 6. Feedback messages suggested by the proposed system to support the user in correcting the back posture.

supervision of an expert as reference skeletons. Experimental results show that the provided feedback helps the user in converging to a healthy posture. The proposed system can be applied in different areas, such as rehabilitation at home (e.g. for stroke survivors [19]–[21]), and in sports, e.g. monitoring people in gyms and as soon as the posture of the user is not the most appropriated, the system generates an alarm with the objective of alerting the user to correct his posture. The user can be notified through audio, smart watch, smart phone, etc. We intend to validate the proposed system in different real scenarios.

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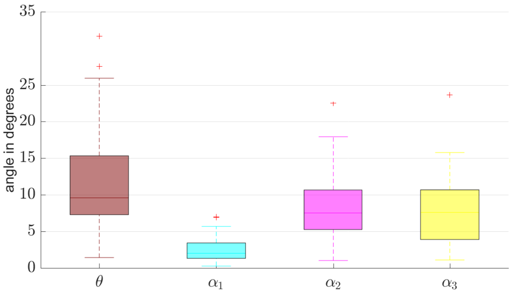
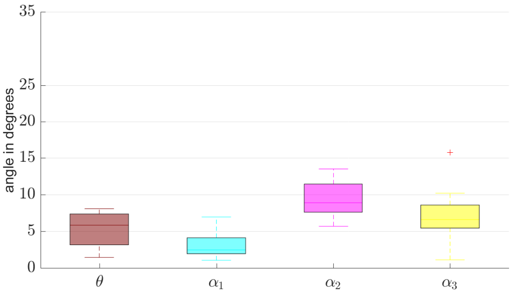


(a) No posture assistance.



(b) With posture assistance.

Fig. 7. Box plot over the critical angles for two different experiments. In the first, no feedback was provided to the subject while sitting in a chair during the working time, Figure 7(a). Figure 7(b) regards the second experiment, where the subject was informed to correct his posture following feedback proposals every time that his posture was considered as incorrect.

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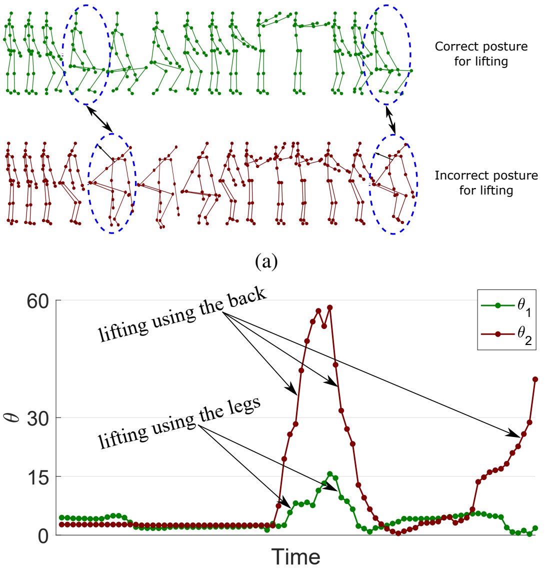
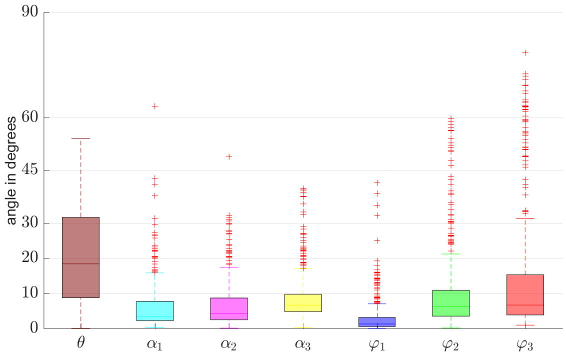


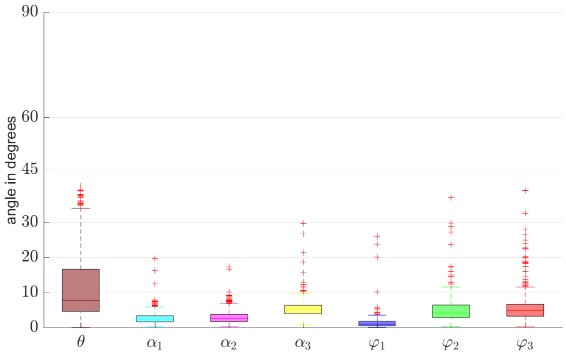
(a)

(b)

Fig. 8. Figure 8(a) shows an example of lifting sequence, where the exercise consists of picking a metallic bar, lift it over the head and leaving it on the floor. The green sequence (top row) illustrates a correct posture, and the red sequence (second row) shows an incorrect posture. The skeletons inside the blue dashed ellipse are examples where the back posture is particularly incorrect. Figure 8(b) illustrates the angle θ over time, where θ_1 regards the correct posture (top row) and θ_2 the bad posture (second row).



(a) No posture assistance.



(b) With posture assistance.

Fig. 9. Box plot over the critical angles for two different attempts of the exercise. Figure 9(a) regards the first attempt, where no feedback was provided to the user while executing the lifting movement. Figure 9(b) concerns the second attempt, where feedback was provided to the user in order to correct the body posture.