Avatar-Facilitated Therapy and Virtual Reality: Next-Generation of Functional Rehabilitation Methods

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***Abstract*— The control of a synthetic human body, or Avatar, is an essential step before the animation process. These two important stages (control and animation) are applied in diverse areas, including video games and 3D animation films. Avatars deserve particular consideration in virtual reality (VR) applications as they represent a fundamental mechanism for interacting with a virtual environment. Avatar's animation require a precise tracking of the user's movements, that must be faithfully replicated, in the 3D scenes, by avatars. The control of a The ability to animate the upper or lower limbs articulation of the human body, in 3D scenes, is a rather complex task, due to the movements to be reproduced with exact closure, by the avatar, while tracking them by using a camera sensor. These problems are mainly associated with the 3D design of human body joints and the exact reproduction of anthropomorphic properties in virtual scenes. This article presents an original framework capable of capturing and reproducing, in real time, the same movements provided by humans, using a Microsoft Kinect camera in virtual landscapes. The proposal concentrates on human's posture failures monitoring by avatars, to improve the posture of people, in rehabilitation stages (victims of stroke or mobility impairment). These scenes contain real motion capture data, which helps to solve postural problems of persons with physical disabilities. Experiments prove the flexibility of the proposed model. During the evaluation phase, we set different scenarios, for an extended analysis of patients' movements through those of avatars.**

Keywords—Motion capture, 3D avatars, Avatar animation, Skeleton tracking, Depth information

I. Introduction

Avatars deserve particular attention in VR applications since they represent a fundamental mechanism for interacting with objects in virtual environment. Avatar's animation re-quire precise detection and tracking of the user's movements that must be faithfully replicated, in the 3D scenes, by the humanoid model (avatar), as illustrated in Fig. 1.

Nowadays, vision-based solutions, such as VR methods are implemented for rehabilitation of persons suffering from physical handicap, including post-stroke and / or persons with a reduced mobility. Victims of stroke accident may often show physical disabilities and even disturbance of postural balance. About two-thirds of stroke survivors still suffer from a lack of leg mobility or muscular dystrophy (a muscle weakness). This inability affects the patient's voluntary movements, such as walking. As a result, this can lead to a decrease in the quality of life of the person. Moreover, conventional rehabilitation techniques produce modest and sometimes delayed effects.

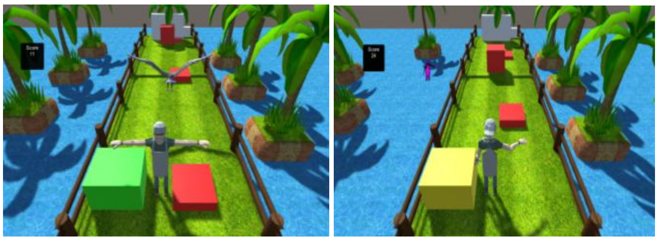

Fig. 1: A mini game (serious game) developed by our team: avatars are used to interact with virtual objects. The user controls the avatar via a kinect camera, for interacting with the surrounding objects (e.g., cubes). The interest is to provide attractive solution for the rehabilitation of disabled patients [20].

The VR style technology is a novel adjunctive therapy that could be applied in neuro- and / or motor-rehabilitation. Virtual Reality-based methods count several helpful features, which allow patients receiving treatment for longer with no embarrassment felt, i.e., VR-based system design aims to lure the human brain of the treatment-related-pain felt and to shift the patient attention, while receiving treatment.

This article presents a simple, yet efficient Virtual Reality application, capable of capturing and reproducing the user's movements, using a kinect camera in virtual landscapes. The proposal focuses on the faithful reproduction and tracking of human posture defects, through virtual reality, using avatars.

In our work, avatars are involved in a therapeutic protocols since they can be considered as an extension of the human body. Thus patient may control the avatar by producing different movements. The ultimate goals are; first, facilitate the study by experts (medical staff) of posture deterioration for people with physical disabilities. Second, provide a low-cost module as an aid to people in rehabilitation phase (people in post-stroke or with a motor disabilities).

Section II presents the different methods and works conducted for rehabilitation with virtual reality methods. In Section III, we describe the proposed algorithm, and Section IV explains in details our proposal. Finally, Section VI provides experimental results. Overall, we show that our approach is a versatile algorithm that is suitable for patients with posture failure problems, particularly at the rehabilitation stage.

II. RELATED WORKS:

For a long time, computer-animated films and video games have been controversially considered as an art form. There's no denying, graphics power and animation realism performance provide unquestionably a unique experience for users. The entertainment industry has widely used motion capture techniques (mo-cap for short), where actors wearing special costumes for movements capturing and adding digital animation to their performances. This approach strengthens the level of realism and affords to the virtual characters as natural interaction as possible. Motion capture offers several advantages over conventional animation methods, such as low latency, complex movements generation, realistic physical interaction and real time information processing (mo-cap can shorten the costs of key-frame-based animation).

Since the inception of VR, motion capture is integrated into content creation process and Human-machine Interaction (HMI) with VR and immersive environments The VR style technology is a novel adjunctive therapy that could be applied in post-stroke rehabilitation. A stroke leaves a major physical disability, which can be resolved by engaging patients in repetitive rehabilitation exercises [1]. However, rehabilitation exercises must be intensively and recurrently performed to stimulate neural remodelling and enhance function [2]. This is not usually done by standard rehabilitation techniques [3]. Innovative technological solutions are increasingly preferable that can reduce the treatment intensity for post-stroke patients. These technologies include VR with mo-cap solvers, which can involve patients in the doses (transformation application) needed to improve the outcomes of physical and cognitive rehabilitation, without the costs and burden of prolonged treatment time [4].

These technologies provide a visual feedback of the movement in real time, increasing the commitment and satisfaction of rehabilitation tasks [5]. However, the use of such technology to support rehabilitation in the subacute setting is very limited [6].

In the literature, there is a wide range of methods that use mo-cap for different purposes. Most of them focus on detecting, monitoring and reconstruction of the human posture. These methods could be classified as follows:

1) Invasive motion capture methods [7], use passive vision systems, such as RGB cameras, and a number of markers stuck on specific regions of the human body, or even portable on it . This type of approach is accurate, but remains troublesome, particularly, for patients in rehabilitation, because it requires wearing of additional equipment.
2) Markerless motion capture methods [8], [9], [10] use computer vision techniques, and no markers are needed for capturing the user's movements.
3) Monocular depth images-based motion capture methods [11], [12], [13], [14], [15], unlike aforementioned motion capture systems require intrusive attachment of markers that are visually tracked with camera. This method can easily achieve a markerless motion capture using only a depth cameras, such as Kinect sensors.

III. METHOD

This paper proposed a VR algorithm based on depth images-based mo-cap approach. We used a Microsoft Kinect-v1 camera as a sensor for depth images capturing. The Kinect camera is advantageous because it is not influenced neither by environmental texture's nature, nor by skin colour.

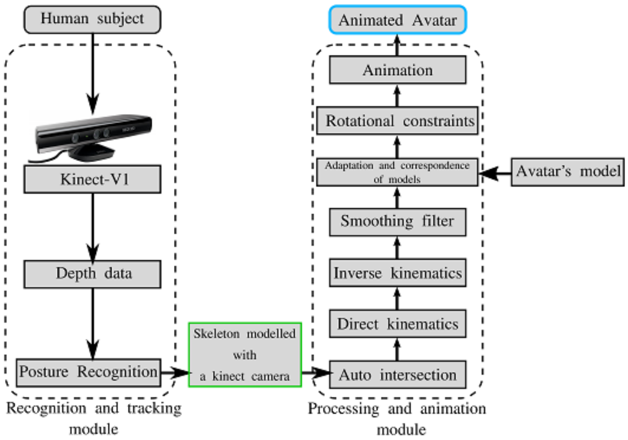

Fig. 2: Overall block diagram of the proposed algorithm.

The proposed algorithm is composed of two principal modules, as shown in Fig. 2:

- **Module 1**, (the diagram's left block in Fig. 2), recognises the human silhouette from its visual appearance and follows it in real time. The effectiveness of this module is relatively stable, for a single person or a group of individuals, captured by the same camera.
- **Module 2**, (the diagram's right block in Fig. 2), processes and controls the avatar animation.

At the first level, the camera provides a depth map data set, which represents the user's silhouette in a skeleton form, as shown in Fig. 2. The result is introduced in the second step that corrects recognition and tracking errors. The ultimate goal is to improve the animation of our avatar.

The proposed approach combines anticipatory tracking of moving objects, and friction-based contact model, between a body and its environment. The designed algorithm would be useful for analysing human posture defects (patient with a physical disability).

IV. ALGORITHM DETAILS

Module 1, uses Microsoft Kinect SDK, to recognise the appearance of human body, the carried out images represent a depth map of the human silhouette, which are tracked in real time. At each frame, the algorithm reconstructs the body posture in 3D, according to the approach proposed by Shotton and .al [16]. The outcome of this phase generates a skeleton model with 3D positions of different joints. This model can be perceived as a hierarchical tree, composed of

20 of joints, the root of which is the pelvis (set of joints connected to each other by rigid links).

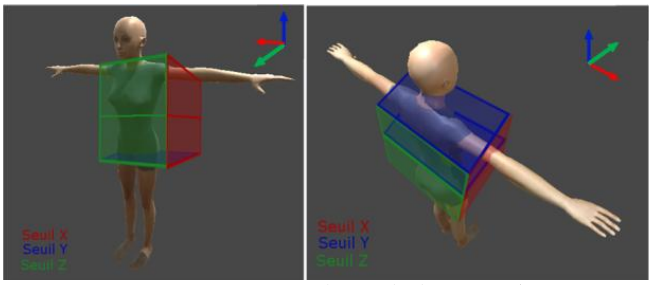

Fig. 3: invisible bounding-box set in the avatar's bust.

Nonetheless, at this level, the algorithm does not introduce, in any case, geometric constraints, for the movement of the joints, and therefore, at the level of the avatar, when the position of one of the joints produces an incorrect value , the skeleton of the avatar, systematically adopts an unrealistic position, which affects the movements of the avatar in the virtual environment.

Module 2 solves the previous problem by introducing a set of treatments before the avatar's animation. The ultimate goal is to improve the animation quality, while preserving realism and naturalness of the avatar. Before introducing any animation to designed avatar. Module 2 consists of seven sub-modules, which are explained as follows:

1) **Auto-intersection** or self-intersection occurs when the joints of the avatar intersect. So, hands (or wrists) of the avatar, must always be placed at a certain distance from the bust. As a solution, we created two invisible bounding boxes around the bust of the skeleton model. The first bounding box has been created at the avatar's neck level, while the second one at the level of its pelvis. These two bounding boxes are defined by distance thresholds set on the three axes (X, Y, Z) of the model (Fig. 3). We exclude the adverse modelling effect by finding the intersection the 3D model's extremities, then its bust is rotated outwards, and finally, we determine the new values of the angle articulation. These new values are obtained by comparing the geometric distances that separate each joint from the pelvis and the neck extremities of our 3D model. Only minimum distance values are kept.
2) **Direct Kinematics**, The avatar is often a fixed mesh, or a vivid mesh that moves conforming to predefined algorithms and actions.
An approach to carry out a compelling immersive virtual reality experience is to capture the user's movements by applying motion capture and map them on a virtual avatar. The 3D positions of the markers can set on a suit, and a kinematics solver recovers the major orientations of the avatar joints that are needed to animate the avatar. However, such approach remains slightly invasive, especially, in a rehabilitation context. Nonetheless, important limitations for a successful em-bodiment of the avatar are the discontinuities produced by self-occlusions and the lack of movement of the arms/ legs, both leading to a diminished sense of body ownership [Bovet et al. 2018]. In such schemes, expand-ing the amount of cameras is not always feasible, and does not entirely deal with the problem. One alternative is to set a kinematics model.
At this stage, we applied the direct kinematics (or forward kinematics) for the orientation values of our skeleton extremities, that generate an incorrect and erratic outputs. The 3D model's hands or feet position are incorrectly detected.

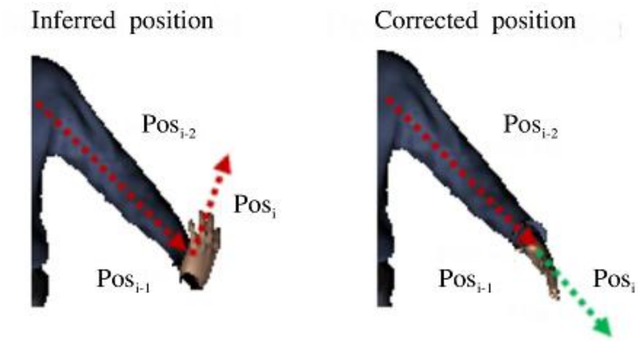

Fig. 4:Correction provided to erroneous outcome at the level of the avatar's hand joint: Direct Kinematics formula applied to the avatar's had joint.

We solve this issue by calculating new position values of the extremities. That involves setting the initial values of 3D bone length, and those of the parent bone rotation, as well as the parent limb position (Fig. 4). The new positions are expressed as follows:

$$Pos_i = Pos_{i-1} + \left(\frac{Pos_{i-1}-Pos_{i-2}}{\|Pos_{i-1}-Pos_{i-2}\|}\right) * l_{i-1} \qquad (1)$$

Where :

- **Pos_i** : is the joint position to correct.
- **Pos_{i-1}** : is the parent joint position to correct.
- **l_{i-1}** : is the length of the link connection between the joint and the corresponding parent joint.
- $\left(\frac{Pos_{i-1}-Pos_{i-2}}{\|Pos_{i-1}-Pos_{i-2}\|}\right)$:Vector of standardized link $i-2$.

3) **Inverse Kinematics**, At this stage, the joints orientation values of our skeleton model gave an erroneous values. So, to solve this issue, we applied the inverse kinematics by the FABRIK algorithm [17]. This algorithm calcu-lates iteratively for correcting the joint position values of the kinematic chain, as shown in Fig. 4.
4) **Smoothing filter** The Kinect camera provides a com-plete skeletal joint structure of the human body, hence, desired articulation data is easy reachable from skeleton form. However, a pre-processing step must be applied for minimising data fluctuation. So, a low-pass filtering process has been adapted to extracted data. The later is formulated as follows:

$$F_k = \frac{1}{n+1}\left(\sum_{i=k-n}^{k-1} F_i + X_k\right), k > n \qquad (2)$$

Where:

- **F_k** is the new filtered position of the joint in current frame.
- ***n*** is the size of the filter window.

- F_i is filtered positions of the joint in precedent frames.
- X_k is raw value of the joint position in current frame.

In this stage, the calculated position value does not exceed the position provided by our skeleton model. However, if this value is wide, the distance between two positions is calculated and if the joint deviation exceeds a predefined threshold, the position is recalculated in order to reduce the distance. It can be expressed as follows:

$$F_k = F_k * \left(\frac{\tau}{\Delta_k}\right) + X_k * \left(1 - \frac{\tau}{\Delta_k}\right) \quad (3)$$

Where:

- τ is the joint deviation threshold.
- Δ_k: is the distance between calculated and the raw
- positions of the joint in frame *k*.

5) **Avatar 3D models** In this paper, we used five 3D mod-els as avatars. Three of them are automatically generated with a 3D avatars based software. inserted parameter settings for avatar modelling. The two remaining avatars were directly ex from the Internet.
6) **Animation** For the animation stage, we first recover the initial spacial position of the user, which is defined as, shift effect of the camera sensor relative to the avatar position in the 3D scene.

   At each frame, the new position coordinates are cal-culated, according to the user movements in the real environment and his initial position coordinates. The movements of the avatar, must be smooth and fluid. So, these requirements are carried out by interpolating between the old and the new positions, according to Peter Kinney et al. approach.

   Their approach manages a particular movements of the hips and the bust. If the user is placed out of the Kinect's range (field of view). Our approach grabs the last known spacial coordinates of the avatar, which are set as initial positional values.

V. VIRTUAL ENVIRONMENTALSCENES ANDUSED AVATAR

In this section, we designed three virtual scenes for visualisation and assessment purposes. Three different scenarios were imagined, as shown in Fig. 5. Therein, user can control the avatar. The three virtual scenes are described bellow:

1) **Scene 1 (Room with Objects):** This is a closed room where the avatar will be able to move freely and will be able to interact with the scenes' objects (see Fig. 7a).
2) **Scene 2 (Studio of Mo-cap)**: Scene representing a studio of motion capture, without objects where the avatar can move freely (see Fig. 7b).
3) **Scene 3 (Mini Game or Serious Game)**: Scene where the avatar must perform a task, that of having to touch the balloons to blow them up, in order to keep the light on the wall always green (see Fig. 5c).

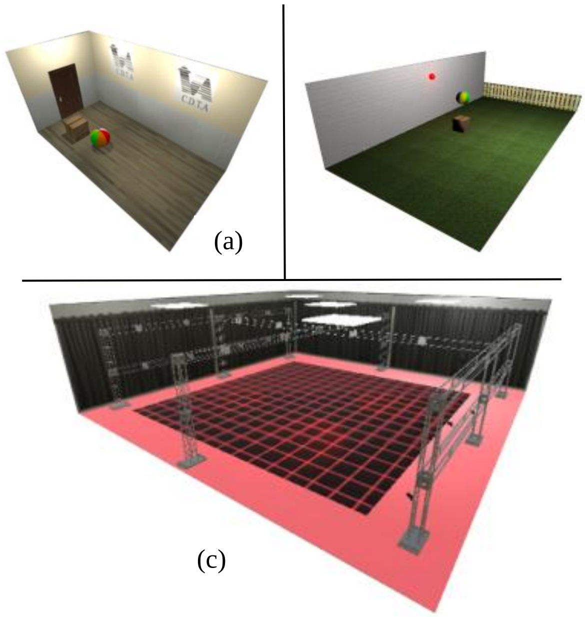

Fig. 5: The different 3D scenes modelled to perform tests: Scene (a) Room with objects, Scene (b) Mini game (Serious game) - Scene (c) Studio of Mo-cap. These images have been captured from Unity3D-based platform (version 2018).

Fig. 6: Screenshot of the mini game developed by our team.

VI. RESULTS ANDDISCUSSION

In the following, we present and discuss the implementation details and obtained results.

A. *Test and Evaluation of our approach*

To show the effectiveness of our approach, we perform assessment protocol into two levels. First, we show the influence of the processing phase over the overall rendering of the animation. Then, we evaluate the influence of 3D models (avatars) on the user's behaviour, while playing a game and performing different tasks.

Our team has developed a mini game (or serious game) for test purpose. The main aim is to touch balloons that appear in the 3D scene.

It projected several balloons in the air, and a player must touch a maximum of them (with the extremities of the avatar's members), to achieve the highest score and to keep the green light turned on during the game session. (see Fig. 6). In the developed mini game, balloons are spherical surfaces with a rigid texture. They appear from three positions, which are marked by cardboard boxes that are cubic shaped surfaces.

During the experiments, we used five avatars, with different shapes and sizes. The main purpose of the first evaluation phase, is to assess the influence of the processing phase over the animation one.

In this paper, got results were interpreted objectively and subjectively. The objective evaluation aims to test the impact of the processing phase over the execution time and the overall accuracy achieved by our approach. Whereas, the subjective evaluation is about the evaluation of participants' perceptions and influence of the processing phase over the capacity of the user accomplishment. In addition, we introduce some restrictions, where only two avatar models were used (Fig. 12). The main purpose is to study the influence of the 3D model (avatar) over the behaviour of a user while performing a specific task.

Last but not lease, we define one specific task (the user has to touch a virtual balloons through the avatar in our virtual scenes). The complexity is that the user may realise his/ her presence within the virtual space, while moving in it.

B. *Evaluation procedure*

Three assumptions are set through of which we evaluate our approach. Those are presented below:

- The accuracy of the animation after the treatment phase. Is this accuracy equivalent or less than that without treatment?
- Is the quality of the animation with the treatment phase better or equivalent than that without treatment?
- The influence of the 3D model of the avatar on the realisation of a task by a user is proven or not.

(a) (b)

Fig. 7:Images of tests conducted by our team in the Lab.

To address precedent assumptions, we selected13 par ticipants of different ages. Their age is between 24 to 47 y/o, with an average of 33:2 y/o, and both genders have been considered, including4 females and 9 men. Subjects are of different tales, between 157 *cm* and 176 *cm*, with an average of 166:4cm and with different body builds (weak build, average build and strong build).

C. *Objective assessment (statistical results)*

A data set has been collected during tests, in order evaluate the execution time and latency of the algorithm. The obtained results are surmised as follows:

- On average, the animation time for a frame without processing is approximately 0:125 *ms* and 3:710 *ms* including processing stage. We noticed that the average processing time is considerably high, by increasing the duration of the executed task (less than4 *ms* for sessions of less than 2 *min*, greater than 10 *ms* for sessions of more than15 *min*). The results obtained reveal that our system must process the data for the animation stage, the results obtained are shown in Fig. 8. The latency calculation between the avatar's movements during the animation phase, including processing stage, and user's movements are shown in Fig. 9.
- We observed two types of latency (Fig. 9). The first type, or displacement latency (Fig. 9), concerns avatar's movement in the virtual scene. The second type, or movement latency, concerns movements made by specific parts of our avatar (Fig. 9).
- The average latency of the movement of the avatar in the scene, or displacement latency, is twice the latency of the movements of the avatar (1.230 *s*) for the displacement of the avatar, 0.660 *s* for the movement of the body (or movement latency).

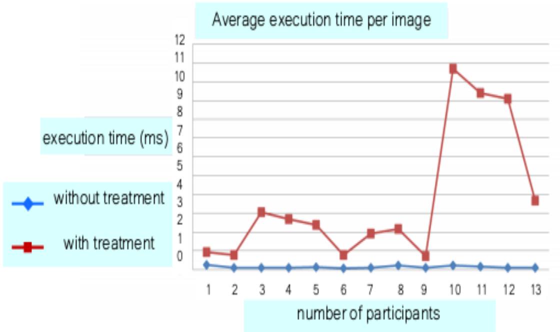

Fig. 8: Graph representing the average execution time per image

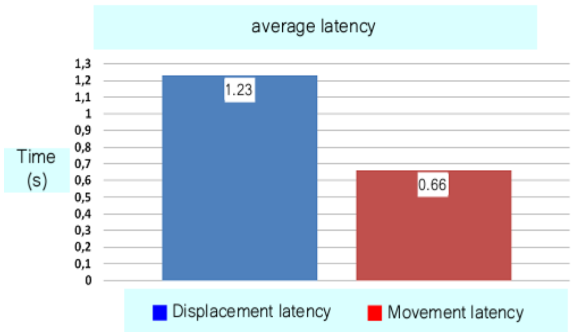

Fig. 9: Histogram of average latency.

The two types of latency are relatively high, the latency of displacement is excessive for real time, which is required for virtual reality.

D. *Subjective assessment*

In this part, participants are to answer two some questions of the NASA Task Load Index (NASA-TLX) form (Fig. 10). In VR applications, questionnaires are still the most common measure, due to the versatility and ease of use.

In addition, several VR studies, use questionnaires and quantitative measures, since this evaluation showed correlations between the objective effects of the experience and the subjective evaluation of participants as it is extracted from questionnaires [18], [16], and [19]. To subjectively evaluate our system, with and without treatment made. this evaluation also concerns the assessment of the avatar type impact over the users' psychological aspect.

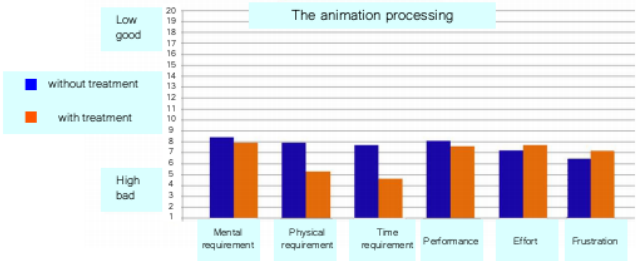

Fig. 10:Results of the NASA Task Load Index (NASA-TLX) rat-ing scale used for subjective, multidimensional assessment protocol for rating perceived workload in order to assess the effectiveness of proposed approach tested with13persons.

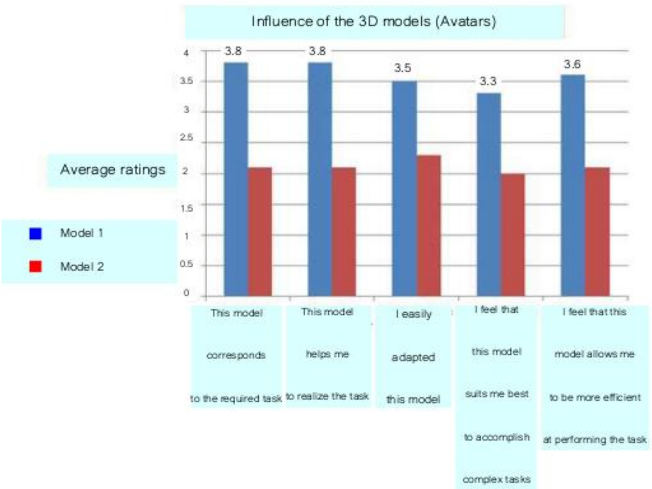

Fig. 11: Results of the questionnaires on avatars

The questionnaire takes into account several independent criteria, which participants must report, based on their experience. The first three criteria are related to the constraints set on each task requested, including physical, mental and temporal requirements. While the other three criteria assess the participants' interactions with a task. This evaluation is about the impact of the avatar's model over the user's psychological aspect, including the efforts made and the frustration generated during test session. The given answers are scored on a scale of20points (ranging from very low to very high).

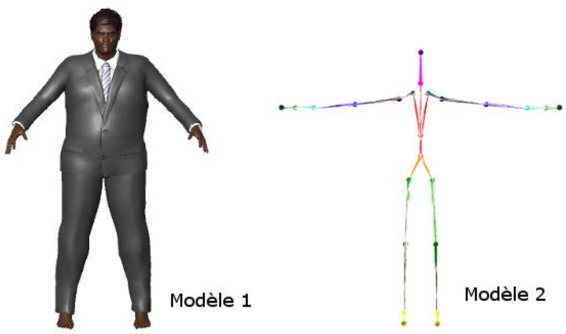

Fig. 12: The two models of avatars used to validate our algorithm: model 1 is dressed with 3D textures in order to look like a human. Model 2 has the skeletal form).

- From Fig. 10, we may notice that the execution of the task during the animation with treatment and without treatment, requires an average attention in view of the degree of mental requirement (8.4 for the animation with treatment and 7.9 for animation without treatment), however, a slight advantage for animation with treat-ment was noted.
- We can also highlight the same remarks, concerning sys-tem performances, where the animation with treatment is considered slightly more efficient with an average of 8.1 against 7.6 for the animation without treatment.
- We noticed a great advantage from the point of view of physical and Regarding the level of physical effort made by users, and their frustration, animation with treatment is slightly higher than the animation without treatment.temporal requirement, for the animation with treatment (7.9 the physical requirement and 7.7 the temporal requirement), where they are weakly necessary compared to the animation without treatment (4.6 for the physical requirement and 5.3 for time requirement).
- Regarding the level of physical effort made by users, and their frustration, animation with treatment is slightly higher than the animation without treatment.

The second form is about the influence of the 3D model type over the use of the system. So, we used a form with five different questions to assess the usability and the satisfaction of the two models. The first 3D model (Fig. 12) has a human form, and the second model has a skeleton form (Fig. 12).

Each participant must answer certain questions, giving a value, on a five-point scale, of "1: strongly disagree" to "5: strongly agree". Once the questionnaire is completed, the average is cal-culated and the reported results are shown in Fig. 11.

- From the results obtained, it was noted that most participants appreciated the use of Model 1 (in human form), compared to the second skeletal model.
- We assume that this is due to the fact that the first model has an anthropomorphic form, which allows an appropriation of the avatar on the part of the user (3.5 with respect to 2.3).
- Participants felt that it is easier to perform the required tasks using model 1 of human form (3.6 against 2.1 for model 2). Participants also felt that Model 1 is more appropriate for performing the tasks requested and also the complex tasks.

VII. CONCLUSION

We have presented an algorithm on interactive virtual reality-based reeducation using mo-cap tech, for people withreduced mobility who have had a stroke or other serious illness. Our proposal focuses on avatars are, involved in a therapeutic protocols since they can be considered as an extension of the human body. Thus patient may control the avatar by producing different movements. The presented algorithm might facilitate handicap analysis by physiother-apists, in order to provide the appropriate set of physical exercises for posture enhancement of people with physical disabilities, e.g., post-stroke patients. Our approach works in real-time and can be considered as a low-cost solution, since it is mainly based on a Microsoft kinect-v1 camera and does not require any high performance hardware for calculations. This study is part of the subacute rehabilitation for functional improvement. Patients can perform targeted functional activities designed by a physiotherapist, and reproduced as a serious game in an RV-based application. These serious games must be supervised by rehabilitation assistants, using gesture control to set the pace of their exercise program. The supervision of physiotherapists or rehabilitation assistants is recommended, in this case, in order to reproduce the study as best as possible under favourable conditions to rehabilitate patients. Obviously, this must be done with a long-term intervention involving qualified professionals of the hospital environment for follow-up.

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