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Supervised Skeleton-Based Reference Movement Adjustment

Abstract: In Medical Training Therapy (MTT) the exact execution of training exercises developed by the therapist is crucial for the success of the therapy. Currently, a therapist has to treat up to 15 patients at the same time on an outpatient basis. The aim of this paper is to provide an assistance system that can evaluate both the quantity and the quality of the movement performed using a goal-oriented model which gives the patient direct recommendations for action through automated, machine-monitored feedback. To implement the therapeutic measures in a targeted manner, it is advantageous to transfer their knowledge to the patients. This would be possible by transferring the therapist's movement into a patient's movement. Under this assumption a movement sequence of the therapist is recorded and a movement reference frame is extracted with the help of a smart sensor, which is made available to the patient as a target movement. The assistance system records the patient's movement in real time, extracts the its skeleton and compares this movement with the reference. Due to anatomical body differences, the reference skeleton must be adapted to the current patient skeleton, otherwise no movement evaluation can take place. By adjusting the bone lengths and angles in the individual frames of the patient's movement the selected sequence can be compared and any movement deviations that occur can be projected in directly in real time onto the patient's 3D avatar as an error image. The patient tries to reduce the errors and in doing so comes closer and closer to the ideal movement of the therapist which guarantees the best possible therapy success.

Keywords: Visualisation, Feedback Control, Assisted Motion Control, Motion Error Detection

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1 Introduction

In Medical Training Therapy (MTT), the exact execution of the training exercises developed by the therapist is crucial for the success of the therapy. Currently, a therapist has to treat up to 15 patients at the same time on an outpatient basis, and the quality of care suffers as a result [4]. Even worse, within a short period of time the patients start to get used to easier compensatory movements that correspond to their physical profile but counteract and prevent the success of the therapy. In current exercise therapy, too many patients are being supervised by too few therapists. Furthermore, the demographic change and the Corona crisis leads to a build-up of acute therapy cases and exacerbates this situation. Marker-based therapy methods have the disadvantage that they fit poorly into the tightly timed course of therapy. The application of markers reduces the available therapy time, is unhygienic and imposes additional restrictions on patients due to the weight and size of the markers. It is necessary to develop a markerless assistance system that can evaluate both the quantity and quality of the movement performed using a goal-directed model and provide direct recommendations for action to the patient through automated, machine-monitored feedback. This would relieve the therapists in their work, as the system corresponds to the demands therapists and relieves them a permanent patient care by implementing their instructions and visually guiding the patients in a suitable form.

The in this work proposed system consists of a smart sensor, which is able to extract a human skeleton and a visualisation unit. The nature of the sensor is designed dynamically. It does not matter which sensor is connected for the skeleton extraction. In the current project status, a Kinect2 is used. However, the system can also work with a Kinect1, Realsense, OpenPose or any other extraction algorithms. It is only necessary to couple the 3D skeleton information to the corresponding mesh.

Our own OpenGL based visualisation [5] guides the patient through the intended movement. For this, a movement reference needs to be created by therapists. This reference assess exactly how a movement sequence that is suitable and

specially prepared for the patient should look like. The reference is individually adapted to the patient in order to achieve the greatest possible therapeutic success. The created reference is stored as a sequence of three-dimensional points, which correspond to the extracted joint points of the sensor. A real-time sequence is required for movement matching and therefor is extracted by a smart sensor. Since the reference created by the therapist and the actual patient skeleton differ in size due to anatomical deviations the reference and the real-time skeleton cannot be compared directly. This requires the conversion adjustment. The extraction adjustment procedure and the implementation of the comparison, as well as the visualisation of movement errors are carried out by this work.

2 Related Work

Previous markerless methods do not continuously monitor movement and do not allow direct adaptation of the therapist's movement to that of the patient. With a proprietary movement coach, idealized movements are compared with the patient's movements [6]. The creation of these ideal movements is time-consuming and is not individually adapted to the patient. The application is also specifically designed for back conditions and does not cover the full range of therapy [2][3].

The company Pixformance [7] use a patented non-free evaluation algorithm for therapy. A training plan can be created from 200 possible exercises via a web interface. By scanning 26 skeletal points, the movements can be matched in real-time and instructional feedback can be given. Error information is displayed textually and via audio.

The eCovery GmbH [8] creates training videos with audio instructions. Artificial intelligence is used to measure and evaluate the specially developed sensor data more precisely. The exercises carried out are precisely documented and document the rehabilitation carried out in therapy practices.

In contrast to the existing systems we differ in mapping the error directly to the avatar [5] and the easy and fast creation of adjustable movement references.

3 Skeleton Adaption and Comparison

The body sizes and the overall anatomy of the therapist and the patient differ. The extraction skeletons cannot be compared directly with the raw data. The three-dimensional skeletal joints of the therapist require a computational conversion to be able to compare with the patient. All changes concerning the

position of the extraction points are only made to the references and thus, the original current incoming skeletal data of the patient are not changed. This means that the original actual skeleton of the patient can still be used for the visualisation of the animated 3D avatar. The visualisation of the avatar always refers to the current patient, which can be described as the individual skeleton adaption. It is necessary for the processing algorithm that the reference skeleton model and the current model coming from the patient do not differ in the number of extraction points, so a one to one matching of all skeleton points is possible. Our approach can cover all skeletal models, so the choice of smart sensor and skeletal extraction method can be interchangeable and individual. The processing chain itself is run through per frame at a frame rate of 60 fps and, due to the relatively few skeletal points, is only calculated on the CPU. The system runs on a mid-range PC with a Core i7 and a Geforce RTX 2060. The patients stand in front of the smart sensor whose current skeletal extraction is compared with a previously recorded reference skeletal extraction movement. The adapted skeletal data are evaluated with regard to their deviation from the current data and, if necessary, detected and visualised as errors.

3.1 Skeleton Size Adjustment

The skeleton adjustment of the all i reference skeleton points R_i to the current skeleton points C_i extracted by the smart sensor is always calculated with reference to the root node C_0 , the central hip joint, of the current skeleton. For this, all reference points R_i are shifted with respect to C_0 . This sets the start position of the reference skeleton to the start position of the current movement.

$$R_i = \sum_{i=0}^n (R_i - C_0) \quad (1)$$

This displacement of R_i does not change the length of the reference bones. To determine the length of the individual bones, it is necessary to iterate over skeletal bone connections list B with length n and calculate the bone lengths l_i as the vector difference of connected points. The lengths of the bones l_i are needed for both, the reference R_i and the current skeleton C_i . The bone connection indices $[j][k]$ for the reference R_i and the current points C_i are identical.

$$l_{R_i} = \sum_{i=0}^n |R_{i_j} - R_{i_k}| \quad (2)$$

$$l_{C_i} = \sum_{i=0}^n (C_{i_j} - C_{i_k}) \quad (3)$$

Since both lengths l_{R_i} and l_{C_i} are now available, a length factor f_i can then be calculated, which indicates the ratio of the current bone length l_{C_i} to the reference bone length l_{R_i} .

$$f_i = \sum_{i=0}^n \frac{l_{C_i}}{l_{R_i}} \quad (4)$$

Now the length l_{R_i} of the reference bone R_i can be adjusted to the actual bone length l_{C_i} by multiplying the factor f_i to the considered bone R_i .

$$S_i = \sum_{i=0}^n (f_i R_i) \quad (5)$$

However, it must be noted that the order of the processed bone indices $[j][k]$ is always organised from the inside to the outside skeleton. This means that the joints that are closer to the center (hip joint) of the body are listed first in the $[j][k]$ connection. The $[k]$ part is always reserved for the outer joints like arms and hands to avoid delay in visual updates of arm and hand-bones. In these cases, contradictory adjustments occur because the calculation of the outer point of a bone is not based on the already updated starting point but on the original point of reference and thus the bone length and alignment are falsified. The searched scaled bones B_s are now the connections $[j][k]$ between the extraction points S_i adjusted in length and position to the current movement.

3.2 Comparison of Skeletons

For the comparison of skeletons all three-dimensional individual skeleton-points of the adjusted reference S are compared with the current skeleton C . The pass index of the

Figure 1: The comparison of a current movement (yellow) to an adjusted reference movement (magenta) after the original reference skeleton (blue) has been adapted.

comparing loop is saved to ensure an ascending order for the currently arriving transaction data. This ensures that the movement develops in the direction of the reference and does not stagnate in execution. The comparison and adjustment of the current skeleton information are in the is shown in the figure 1. Only previously selectable joints of the reference are compared. In this case, only the shoulder joint and the elbow and wrist joint are used. The necessary individual skeletons are visualised in different colours for a better idea of the working method. The current, unchanged real-time skeleton C is the yellow line in figure 1. The blue skeleton is the original of the reference R and represents the recording of the therapist. As can be seen in figure 1, the anatomy is different between therapist and patient. In order to equalise these differences in size, the original blue reference skeleton R was adjusted to the size of the current yellow skeleton C . The scaled skeleton S is shown in magenta. The coloured points indicate the extracted joint points in each sequence, which are connected and form the skeleton. The white lines connect the original reference skeleton to the current skeleton. Grey lines connect the points of the fitted skeleton to the patient's current one. The lines serve as a tool to identify more precisely which individual points are being compared. The coloured boxes indicate whether the observed joint of the scaled reference skeleton S is within a defined three-dimensional range Δ of the current skeleton C . For this, each scaled joint S in the boundaries are calculated.

$$\sum_{i=0}^n (S_{i_x} - \Delta_x) < C_{i_x} < \sum_{i=0}^n (S_{i_x} + \Delta_x) \quad (6)$$

$$\sum_{i=0}^n (S_{i_y} - \Delta_y) < C_{i_y} < \sum_{i=0}^n (S_{i_y} + \Delta_y) \quad (7)$$

$$\sum_{i=0}^n (S_{i_z} - \Delta_z) < C_{i_z} < \sum_{i=0}^n (S_{i_z} + \Delta_z) \quad (8)$$

Figure 2: A deviating movement is detected as an error and leads to a coloring of the surface segments involved indicating the movement error [5].

If the points C_i are in defined bounding box range $(x_{min}, x_{max}, y_{min}, y_{max}, z_{min}, z_{max})$ they are displayed in green. In case of an error, they are visualized in red.

In figure 2, no match of the current skeleton with the matched reference has been found. The error movement originates from the arm. To make this clear, all skeletal connections involved are coloured in traffic light colours. This allows the patient to visualise the movement deviation directly in real-time on the connected avatar. The movement can now be adjusted immediately to avoid the error of movement deviation. This can prevent the patient from training compensatory movements.

4 Conclusion and Future Work

Our work presents a scaling algorithm that compares and evaluates the individual sequences of an extracted skeletal movement with an aspired reference movement. The aim of reference adaption is to determine the quality of the current movement with respect to the reference movement. In this way, deviation errors can be detected and displayed in real time. The advantage of this approach is the rapid creation and availability of reference movements. These can be created within a short time and are independent of the anatomical size of the creator to the user. Furthermore, the system depends not on a predefined hardware and can be used with every actual depth sensor and skeleton extraction algorithm. By staying only within the allowed range of motion, the patient completes the exercise exactly as the therapist designed it. Previous studies have shown that assisted movement sequences can increase the success of therapy [1].

In the future, it is planned to extend these reference movements and the adaptation to other fields of application.

The extraction of hand skeleton points makes it possible to extend therapeutic measures to the evaluation of hand movements. In addition, constantly recurring hand movement patterns could be referenced and used for industrial purposes in production instructions. In this way, production workers could be trained and their work steps checked. Another application area is facial point extraction. This supports speech therapy and enables permanent training even in the home environment.

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