Method for Prediction of Motion Based on Recursive Least Squares Method with Time Warp Parameter and its Application to Physical Therapy

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***Abstract*—We build an exercise therapy support system for children with disabilities that applies artificial intelligence technology. In this study, a 3DCG character shows a model body-building exercise, and at the same time provides feedback such as calling out to the trainee. At that time, to make the exercise therapy work more effectively, the trainee's movement is attempted to be corrected by notifying the trainee with a voice or other means before the trainee's movement deviates significantly from that of the 3DCG character. Since there is inevitably a delay between the movements of the 3DCG characters playing the role of the trainee and the trainer, it is necessary to predict this delay using time series analysis. The Recursive Least-Squares estimation: RLS method was used for this prediction method. In addition, the similarity of the movements of both companies was evaluated using the Dynamic Time Warping: DTW method, and the time warp calculated in this process was used as input for the RLS method. The results of the experiment confirmed that the predictions were made with sufficient accuracy and that when the degree of similarity was low, the 3DCG character playing the trainer's role spoke to them, leading to improvements in the trainees' movements.**

***Keywords*—Exercise therapy; disabled person; body-building exercise; 3D character; Recursive Least-Squares estimation: RLS method; Dynamic Time Warping: DTW method**

I. INTRODUCTION

There are various body-building exercises as exercise therapy for children with disabilities [1]. Physical training is important not only for overcoming functions that are impaired by a disability, but also for mental and emotional stability, releasing stress, adapting to a group, and developing social skills. However, because children with disabilities have significantly different physical fitness characteristics depending on their stage of growth and the type and severity of their disability, it is necessary to provide guidance tailored to everyone, rather than one-size-fits-all guidance. It is also important to determine the appropriate amount of exercise for the trainee. However, many years of teaching experience and knowledge are required to select the type and amount of exercise that are appropriate for the trainee. Therefore, it is important to develop trainers who can select body-building exercises that are suitable for each individual and show them model movements.

In this research, we build an exercise therapy support system for children with disabilities that applies artificial intelligence technology. In this study, a 3DCG character shows a model body-building exercise, and at the same time provides feedback such as calling out to the trainee. At that time, to make the exercise therapy work more effectively, the trainee's movement is attempted to be corrected by notifying the trainee with a voice or other means before the trainee's movement deviates significantly from that of the 3DCG character.

Since there is inevitably a delay between the movements of the 3DCG characters playing the role of the trainee and the trainer, it is necessary to predict this delay using time series analysis. The Recursive Least-Squares estimation: RLS method [2] was used for this prediction method. In addition, the similarity of the movements of both companies was evaluated using the Dynamic Time Warping: DTW method [3], and the time warp calculated in this process was used as input for the RLS method. This approach is original. Namely, using time warp information as a time series of data, trainee's action is predicted with a one-period ahead prediction based on RLS method is a new method. Conventional methods evaluate a user's action after it is completed, but the proposed method provides instructions to the user in real-time while the user is performing the action. By providing instructions to users in real-time, it is expected that the learning effect will be improved compared to conventional methods.

Meantime, using ThreeDPose [4], save the 3DCG character of the trainer and the movement of the trainee, that is, information on the skeletal coordinates of the positions and angles of each joint of the human body, in CSV formatted data. Based on this information, the difference in movement between the two is detected, and time-series prediction (one-period ahead prediction) is performed considering the delay in movement between the two, if the difference is likely to become large, a 3DCG character playing the role of a trainer is created. Accordingly, the character makes suggestions to the trainees.

The results of the experiment confirmed that the predictions were made with sufficient accuracy and that when the degree of similarity was low, the 3DCG character playing the trainer's role spoke to them, leading to improvements in the trainees' movements.

In the next section, related research works are described followed by the proposed methods. Then, experiments are described followed by a conclusion with some discussions.

II. Related Research Works

As for the RLS method related research works, there are the following papers, prediction method for time series data including many missing data based on RLS method is proposed [5]. On the other hand, limits of application of RLS method in parameter estimation of Kalman filter is clarified [6].

Meanwhile, there are the following papers which deals with time series analysis, prediction method for time series of imagery data in eigen space is proposed [7]. On the other hand, Geography Markup Language: GML based representation of time series of assimilation data and its application to animation content creation and representations are created [8]. Meantime, recovering method of missing data based on the proposed modified Kalman filter when time series of mean data is known is proposed [9]. Furthermore, time series analysis for shortened labor mean interval of dairy cattle with the data of BCS, RFS, weight, amount of milk and outlook is conducted [10]. Moreover, Recursive Least Square: RLS method-based time series data prediction for many missing data is attempted [11].

Meanwhile, there are the following skeleton related research works, 3D skeleton model derived from Kinect depth sensor camera and its application to walking style quality evaluations is proposed [12]. Human gait skeleton model acquired with single side video camera and its application and implementation for gender classification is attempted [13]. Furthermore, human gait skeleton model acquired with single side video camera and its application and implementation for gender classification is also conducted [14].

On the other hand, there are the following similarity related research works, Fuzzy Genetic Algorithm: FGA for prioritization determination with techniques for order performance by similarity to ideal solution is proposed [15].

Meantime, there are the following matching related research works, Ground Control Point: GCP acquisition using simulated Synthetic Aperture Radar: SAR and evaluation of GCP matching accuracy with texture features is attempted [16]. Also, Dynamic Programming: DP matching based image retrieval method with wavelet Multi Resolution Analysis: MRA which is robust against magnification of image size is proposed [17]. On the other hand, methods for wild pig identifications from moving pictures and discrimination of female wild pigs based on feature matching methods are proposed [18].

Meanwhile, there are the following prediction-related research works, a comparative study between eigen space and real space-based image prediction methods by means of the Autoregressive Model: AR is conducted [19]. Also, a comparative study on image prediction methods between the proposed morphing utilized method and the Kalman filtering method is conducted [20]. A prediction method for time series of imagery data in eigen space is proposed [21]. On the other hand, image prediction method with non-linear control lines derived from Kriging method with extracted feature points based on morphing is proposed [22].

III. Proposed Methods and System

A. System Overview

The motivation of this study is to provide guidance tailored to everyone, rather than one-size-fits-all guidance for physical therapy, training to disabled person. It is also important to determine the appropriate amount of exercise for the trainee. Therefore, encouragement to trainees is very important. Fig. 1 shows an example of an encouragement system using 3DCG character in a personalized basis for physical trainings. If the trainee action is just the same as 3DCG character of trainer action, then 3DCG character praise the trainee and if the trainee action is differed from the trainer action, then 3DCG character encourage trainee with the correct message.

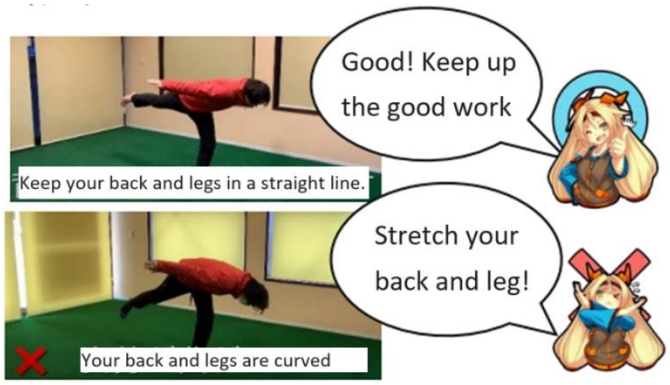

Fig. 1. Example of encouragement system using 3DCG character on a personalized basis for physical training.

Always trainee follows trainer's actions so that time delay would occur. Therefore, prediction of trainee action would be required for the creation of the most appropriate message for correction. Also, distance measurements between trainer and trainee actions are required as well. RLS method is used for the prediction while DTW is applied for distance measurements. To measure the distance of joint positions and angles between trainee and trainer, skeletons which are derived from ThreeDPose are used.

B. Procedure

The procedure of the proposed method is as follows:

1) Analysis of trainee movement by skeletal estimation: Extract the trainee's three-dimensional coordinate data using skeleton estimation technology (ThreeDPose),

2) Creating trainers' and leaners' movements using 3DCG characters: Create exercise motion animations of 3DCG characters to present sample body-building exercises which are made by the trainer.

3) Calculating the similarity between the ideal trainer's action and the trainee's action using DTW: Find the ideal trainer's movement in the body-building exercise and the movement of the trainee's skeleton and calculate the degree of similarity between them using DTW.

4) Judging the quality of physical movement in trainees: Determine the quality of the trainee's body movement based on the similarity obtained in Eq. (3) and the trainee's skeletal coordinate data.

5) Predicting trainee movement using RLS: Predict abnormal behavior (large discrepancy between both movements) in advance using the RLS method based on the similarity obtained in Eq. (3)

6) Make a caution (give a notice) to the trainees to correct their movement (behavior).

C. Methods

1) Creation of 3DCG characters: Unity3D is a game engine with a built-in IDE developed and sold by Unity Technologies. Content can be developed mainly by programming using C#. It is compatible with cross-platforms such as PC (Windows, macOS), mobile (iOS, Android), web browsers (WebGL), home game consoles (PlayStation 4, Xbox One, Nintendo Switch, etc.), and supports VR/AR/ It also supports content development for MR equipment.

2) Detection of skeleton: We use skeleton estimation AI to extract the coordinate information of the model 3D character and the learner. ThreeDPose, the skeleton estimation system used this time, has a program inside the script that manages the current coordinate data, and each script is written in C#. Information such as rotation and position is stored in it, and we use this to extract and understand the movements of the learner.

Python/MediaPipe is an alternative to a motion capture method, which is a technology that converts the movements of people and objects into data. With motion capture, it is possible to check the player's movements in real-time. The gymnastics movements performed by the trainer were filmed in advance, and the coordinates and angles of each body part and joint were converted into time-series data. By using this data as correct gymnastics movements, the trainee's movements captured with a web camera are scored.

3) Similarity measurement: DTW (Dynamic Time Warping) A method for comparing and matching time-series data and temporal fluctuations. The focus is on time warps. It is mainly used in various fields that require comparison and matching of temporal patterns, such as speech recognition and action recognition.

4) Prediction of movement: RLS method: The model that is often modeled using the RLS method is the ARX (Auto-Regressive with eXogenous input) model (it is not a particularly complex model, and the image is the output of 1, 2,…,n steps before or the output of 1, 2,…,n steps before). is a model whose input depends on the current output. The features are as follows, Predictions are stable even with little data, Prediction accuracy does not decrease significantly.

5) Quality evaluation of trainees' movement in comparison to the movement of trainers. The ideal amount of movement can be determined from the amount of movement of the trainer. Using this method, ideal coordinates are calculated and compared with the actual movements of the trainee.

IV. Experiment

A. Skeleton Extraction

Coordinates were extracted by comparing with a model 3DCG character. Information on each joint was managed using a C# script under the name "jointpoint." This stores information such as rotation (angle) and position (coordinates). An example of skeletal data read by ThreeDPose is shown in Fig. 2.

Fig. 2. Example of skeletal data read by ThreeDPose.

B. Comparison of Actions Between Trainer and Trainee

The method of calculating pass/fail differs depending on the exercise, but let's use the exercise of raising the left hand as an example (see Fig. 3). First, calculate the amount of movement from the change in coordinates before and after exercise. If the amount of movement of the trainer data is the ideal amount of movement, calculate the amount of movement of the trainee in the same way. By comparing these, it is determined whether the user is performing the same movements as the trainer.

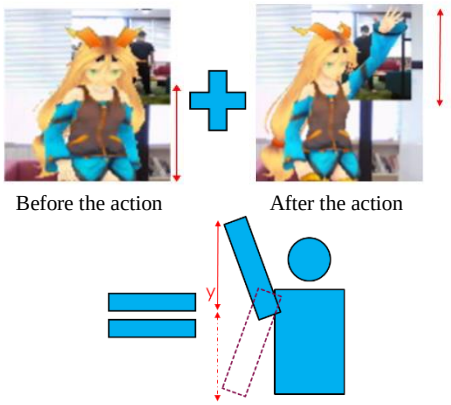

Fig. 3. An example of the exercise of raising the left hand.

We calculated the similarity using the speed of each part of the trainee and trainer characters. However, this method defeats the purpose of determining the similarity of "movements" because the speed at which the trainees move their bodies differs. Furthermore, there is also the problem that the speed changes rapidly, such as increasing, decreasing, or becoming 0, making the calculation of similarity unstable as shown in Fig. 4. Therefore, we conducted an experiment to perform DTW using information obtained through observation. An object that serves as an observation device is placed in 3D space, and it is programmed to collect information A and information B seen from the observation device. In this research, we mainly collect the coordinate distance between the observation device and the learner, and the coordinate distance between the observer and the 3DCG character as shown in Fig. 5.

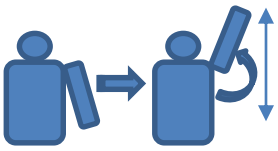

Fig. 4. Similarity calculation using the speed of each part of the trainee and trainer characters.

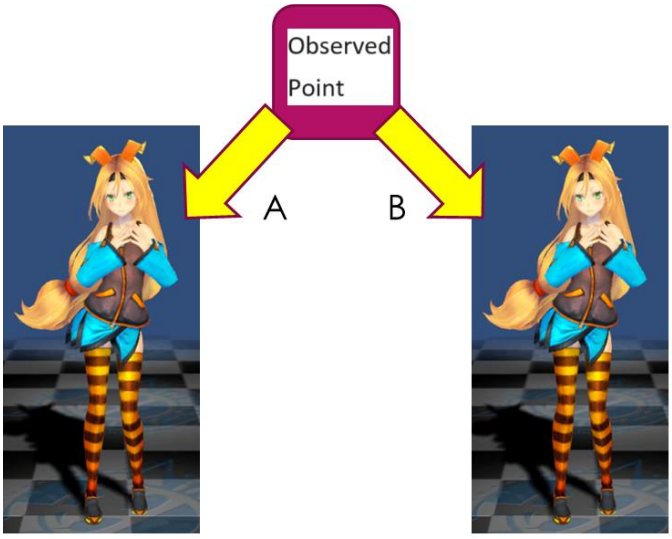

Fig. 5. Coordinate distance between the observer and the 3DCG characters.

C. Calculate Similarity by DTW (DTW Distance)

The distance from the observation point to each part of the trainee and the distance to each part of the trainer was recorded for every frame. Fig. 6 shows an example of the time series data of joint points.

Also, Fig. 7 shows an example of the time series of corresponding joint points connected. The graph below shows the difference in similarity when comparing the data of the upper trainer and the data of the lower trainee.

D. One-Period Ahead Prediction of Trainee's Actions

Next, we will explain how to predict learner movements (surveys and experiments) to eliminate feedback delays. To explain, there is a time delay between when the system detects the learner's movements and when the learner calls out to them. Even if the system can detect the learner's movement, the learner's behavior may have already finished by the time the system detects the learner's abnormal behavior and calls out to him. Therefore, we thought that it would be possible to correct the movements by predicting the movements of the learner using time-series data from time warp and giving feedback such as calling out to the learner before the learner engages in abnormal behavior.

LightGBM is a typical prediction method based on linear regression. Therefore, firstly, the LightGBM is tried to predict the actions of trainer and trainee. An example of the result is shown in Fig. 8.

	A	B
1	1.231215	
2	1.231215	
3	1.231215	
4	1.231215	
5	1.231215	
6	1.231215	
7	1.231215	
8	0.96367	
9	1.068625	
10	1.601985	
11	1.555619	
12	1.549107	
13	1.128521	

	A
1	1.037787
2	1.037956
3	1.037956
4	1.037956
5	1.037956
6	1.037956
7	1.037956
8	1.037956
9	1.056942
10	1.059628
11	1.061921
12	1.06026
13	1.060333

Fig. 6. Example of the time series data of the observed joint points between trainer and trainee.

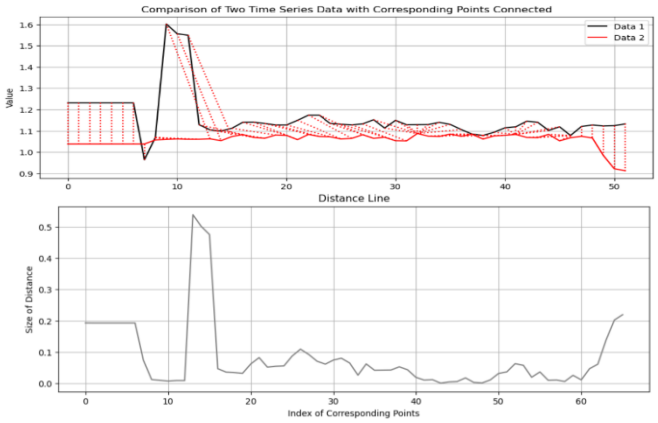

Fig. 7. Example of the time series of corresponding joint points connected.

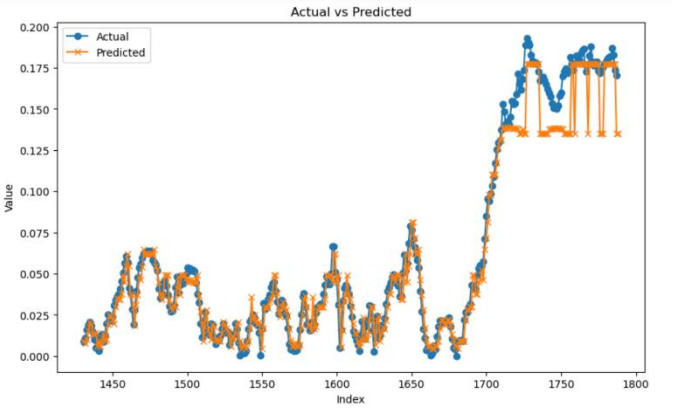

Fig. 8. Example of the prediction of action based on LightGBM.

As shown here, the prediction results with LightGBM can predict to some extent in the first half, but the prediction accuracy drops significantly in the second half. Also, adjusting various hyperparameters is made, but it did not stabilize. Furthermore, predictions were difficult with little data.

The actual DTW distance and the RLS predicted value match to some extent, and if this data can be incorporated into the system, it is inferred that it will be possible to predict the trainee's movements in advance and provide feedback based on that prediction.

Fig. 9 shows an example of one period ahead prediction of the action based on RLS (Comparison of the action between actual action and the predicted action).

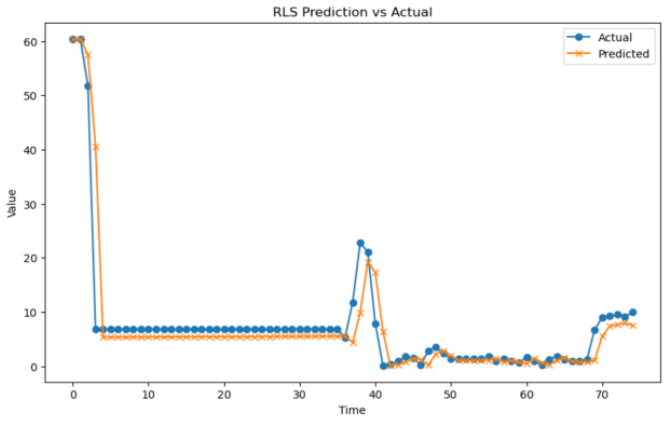

Fig. 9. Example of one period ahead prediction of the action based on RLS (Comparison of the action between actual action and the predicted action).

V. Conclusion

In this study, we build an exercise therapy support system for children with disabilities that applies artificial intelligence technology. In this study, a 3DCG character shows a model body-building exercise, and at the same time provides feedback such as calling out to the trainee. At that time, in order to make the exercise therapy work more effectively, the trainee's movement is attempted to be corrected by notifying the trainee with a voice or other means before the trainee's movement deviates significantly from that of the 3DCG character.

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Future Research Works

Further experiments are required for evaluation of the effect on physical trainings using the proposed methods and the system.

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