Proceedings of the 3rd International Conference on Signal Processing and Machine Learning
DOI: 10.54254/2755-2721/4/20230471

# The application of neural network approaches for physical rehabilitation

**Duoqi Liu**

Shanghai SMIC Private School, No. 169, Qing-Tong Road Pudong New Area, Shanghai, China 201203

lhongjun.e08sh2@ceibs.edu

**Abstract.** Physical rehabilitation is essential for a large number of patients around the world to recover from their disabilities. However, conventional methods of rehabilitation were expensive and difficult for majority of patients to access. This paper presents studies with neural network-based approaches that solve this problem are reviewed in this paper. The methods are divided into three main categories: stroke rehabilitation, injury rehabilitation and other rehabilitations. The common methods reviewed are Convolutional Neural Network (CNN), Support Vector Machine (SVM) and Recurrent Neural Network (RNN). There are various rehabilitation datasets reviewed in the paper, which all included pictures and videos of both patients and healthy people preforming a series of movements. The sensors used in experiments to capture patients' movements are also summarized in this paper. The paper reviewed few algorithms able to model a 3D human skeleton based on the data collected by sensors. Evaluation metrics reviewed includes Discrete Movement Score, rule-based and template-based scoring methods. K-Nearest Neighbor (KNN) and Dynamic Time Warping (DTW) distance function were commonly used in template-based evaluation methods. The results in researches reviewed indicate that neural network-based rehabilitation methods are able to satisfy most demands, and improved efficiency, making it affordable and accessible to more patients.

**Keywords:** Physical rehabilitation, Neural network, Machine learning, Movement evaluation method.

## 1. Introduction

Physical rehabilitation, commonly applied in the field of medical science, is a method that can assist patients who experienced physical disabilities or impairments to restore their physical abilities after surgery [1]. A variety of studies had verified the essential role of physical rehabilitation during the process of recover for an injured patient [1-3]. Statistics from the World Health Organization (WHO) shown that 15% of the world population suffer from disabilities of different extent, and the demand for rehabilitation is at an increasing rate [4]. However, this indispensable healing care for most disability patient is sometimes impeded by some factors, especially in lower-middle income countries. Cost is one of the burdens that hinders impoverished patients to get access to rehabilitation treatments. According to the Medical Expenditure Panel Survey made by the US federal government in 2007, physical rehabilitation programs with the participation of 9 million adults conducting 88 million courses cost about 13.5 billion dollars in total [5]. Accuracy is another problem. Research had revealed that conventional ways of observing rehabilitation usually have considerable deviation [2]. Using conventional methods to deal with quantitative amount of patient is also impossible [3]. To solve these

DOI: 10.54254/2755-2721/4/20230471

problems, computers with neural network, a combination of machine learning algorithms within different nodes and layers [6], using particularly visual identification and data analysis in this case, were introduced and started to apply in physical rehabilitation.

In the past few decades, machine learning was already used. However, the performance did not satisfy users, so neural network was introduced [1]. Robots equipped with RGB-D sensors and cameras are used in patients' home [7]. Force sensors are also installed to measure the pressure each foot exerts to the ground. The absolute mean square error of the sensor is ± 0.3 cm [8]. With these high-accuracy instruments, precise motions of patients can be captured by cameras and sensors [2]. By interpreting feature engineering, which is a process of selecting, analyzing, and transforming raw data into datasets that can be use in supervised machine learning, can compute the images [9,10]. The images can further be evaluated to form 3D human skeletons by using machine learning regression, and deep neural network can analysis the quantitative data [3]. To be specific, scoring method is used in this evaluating process. By using machine learning algorithms including Support Vector Machine (SVM), distance functions, and probability density functions, computers can export the score [9-11]. Based on the numerous datasets existing, the results computed are compared and also used to optimize the datasets [11-13]. With the involvement of the Internet, the results could also be upload to servers to proceed further evaluations, including online estimations made by doctors [14]. Finally, patients can get visual feedback through their computer screens, therefore acknowledging their current recovering progress and make adjustments if necessary [7].

These recent features solved the majority problems existing in conventional rehabilitation. The latest development of physical rehabilitation along with neural network and machine learning now enables patients to do home-self-trainings and online estimations. Nowadays, as research indicates, more than 90% of all the rehabilitation sessions are performed at home [12]. Under this circumstance, the cost of the recovery course is significantly reduced, the accuracy improved, and much more efficient to analysis a vast amount of data [6-10]. These recent developments benefit more patients, especially living in lower-middle income countries, by providing an efficient and convenient access to rehabilitation, which used to be expensive and complicated [4, 7].

The goal of this paper is to summarize the application of neural network in physical rehabilitation. With the rapid development of technology, this field is relatively new and only have a few existing reviews. The reminder of the review is organized as follows. First, section 2 discusses the methods related to neural network used for physical rehabilitation based on different scenarios. Then, the results and discussions based on the methods reviewed are presented in section 3. The discussion will analyze all the researches mentioned in the preceding text and indicate insufficient parts of pervious researches. Finally, section 4 briefly summarizes the paper and gives a conclusion.

## 2. Methods

### *2.1 Stroke Rehabilitation*

Stroke is a common and serious illness that requires rehabilitation. In many countries, stroke is the second or third disease that causes death. In a study [2], robots with the function of automatic detection were used. In the experiment, researchers setup the robot with multiple sensors and cameras that can capture patients' movements. Kinect, a device developed by Microsoft that was originally designed for motioning sensing on Xbox 360, was also used in rehabilitation. Kinect is equipped with RGB-D sensors, and have the advantage of low-cost. Multiple research groups choose to use Kinect in their experiment and found it feasible [1, 2, 7, 8]. To analyze the data collected, researchers used a recently released dataset called Toronto Rehab Stroke Posture (TRSP), which includes the sample of both healthy and disabled people, enabling a comparison and scoring range between disabled patients and normal people's performance [2]. To produce the dataset, both groups of people performed a series of motions, and was recorded by sensors. The dataset was processed by analyzing the x, y, and z axes of the pictures captured and produce a clear view of the joints, direction, and range of a single movement. By a combination of supervised machine learning algorithms, including Support Vector Machine (SVM) and Recurrent Neural Network (RNN), the postures of the participants were classified. To improve the training method, another group of researchers developed a more efficient algorithm using deep neural

DOI: 10.54254/2755-2721/4/20230471

network [3]. Their algorithm involved Convolutional Neural Network (CNN) to extract the key points in the pictures. The input volume of the model was 124×12, which the training dataset is 124 frames extracted from the videos captured, and the depth is 12 [3].

### *2.2 Injury Rehabilitations*

A considerable number of disables are caused by injuries; rehabilitation for these patients is also important. To reduce the pressure for therapists and increase the efficiency, neural network is also applied. Pose estimation and tracking are commonly used. From the data captured by sensors, the computer can process it into a 3D skeleton model [10]. To achieve this, researchers designed the algorithm using SVM and CNN. The program first identifies the outline of human body by visual identification using CNNs. Then, 15 key joints that can represent the whole human body would be selected [10]. Finally, using these nodes, a human skeleton model would be produced. By using SVM, the program can kept optimize the performance of regression to make the model more accurate [3,9].

### *2.3 Other rehabilitations*

Neural network-based method will also be needed in other rehabilitations, such as the ones caused by surgery, disease or illness, or functioning decline because of aging. To restore from these situations, various methods might be chosen depending on the specific condition of the patient. Neural network frameworks including CNNs, SVM, RNN, et al. were some of the methods used [1,7,11,12,15].

### *2.4 Evaluation Metrics*

With the data analyzed and processed, evaluation methods, or scoring methods, are used to evaluate the performance of the patient and provide results and suggestions. Discrete Movement Score is the simplest method, it only determines whether the movement is correct or incorrect. This method usually uses K-Nearest Neighbor (KNN), which could find the nearest group (in this case correct or incorrect) the input belongs to [1,11]. A more advanced and common method is template based, including Dynamic Time Warping (DTW) distance function and probability density function [1]. DTW is an algorithm that was widely used in the field, it can compare two temporal sequences, which could vary in speed, direction, pose, et al [1,7,11]. Probability density is an approach including a probabilistic model that can estimate the probability of each score the motion will receive [7]. Another evaluation method is rule based approach. It uses a set of existing rules that demonstrate the standard movements to compare with the corresponding motion that the patient performed [1]. Depending on different scenarios, various scoring functions might involve in the process of producing the final result.

DOI: 10.54254/2755-2721/4/20230471

## 3. Results and Discussions

**Table 1.** Summary of the methods and results for certain rehabilitation experiments.

| Reference | Method | Dataset | AUC | Accuracy | Scoring Method | Sensors | Objective |
|---|---|---|---|---|---|---|---|
| Lukasik et al. [2] | SVM, RNN | TRSP | 0.79 | 85% | Rule-based | Kinect | stroke |
| Yang et al. [3] | CNN | videos | 0.71 | 95% | Template-based | Single camera | all |
| Escalona et al. [4] | Skeleton 3D estimation | - | - | 92% | DTW | Kinect | others |
| Baptista et al. [7] | Skeleton 3D estimation | - | - | $\pm 0.8^{o}$ error | DTW | Kinect v2 | stroke |
| Tao et al. [10] | Kinect2 open SDK | SPHERE | 0.75 | 84% | Template-based | Kinect v2 | injury |
| Liao et al. [12] | CNN | UI-PRMD | - | 90% | Probability density | Kinect | all |
| Yu et al. [13] | GCN | EHE, UI-PRMD | - | 98% | KNN | Kinect v2 | all |
| Liang et al. [14] | LSTM | - | - | - | - | - | stroke |

From the methods listed in preceding texts, it is obvious to see that rehabilitation methods under various scenarios are highly similar. SVM, CNN, RNN et al. are most commonly used in all types of physical rehabilitations [1-4,8-10]. Graph Convolutional Network (GCN) and Long Short-term Memory (LSTM) are also sometimes used [13,14]. The accuracy (85%-98%) of the methods involving neural network are satisfiable for most applications. There are two main kinds of scoring methods, which are KNN and template based DTW. By using template based scoring method, including DTW and KNN, the accuracy is usually higher than other methods.

Although there are many different types of datasets listed in Table 1, such as Elderly Home Exercise (EHE) and University of Idaho - Physical Rehabilitation Movements Data Set (UI-PRMD), the contexts in them are highly similar. These datasets all include pictures or videos of both patients and healthy people doing a set of movements.

From the results, it could be analyzed that the neural network methods can be generally used in all types of rehabilitation. Moreover, the datasets can also be used among different method, meaning that it is possible to combine the datasets to result in a more comprehensive one. Also, almost every experiment used Kinect or devices similar to Kinect as their sensors. Considering all the factors above, most of the algorithms, datasets and sensors are versatile, resulting in that the cost of developing the neural network rehabilitation system would be lowered, and the efficiency would improve. Neural network-based methods had achieved performance same or even better than human in the evaluation of rehabilitation, pose recognition, and analyze with quantitative patients' data.

## 4. Conclusion

This paper presents a review of recent neural network-based methods applied in solving problems existing in conventional physical rehabilitation. Methods including RNN, CNN, SVM, et al. are most commonly used in the field. Kinect or other sensors similar to it are widely used by various research teams. Modeling a 3D human skeleton is an effective way of analyzing the data collected by sensors. Scoring methods usually are rule-based and template-based. Template-based method, involving DTW and KNN are more accurate. Although various datasets were used in researches, it all includes pictures and videos of patients and healthy people doing a series of movements. The recent progress of neural network methods can satisfy most scenarios of physical rehabilitation. More patients are able to get access to rehabilitation more convenient and at lower costs. However, the methods reviewed in the paper can only process static frames of motions, not able to process with dynamic videos. In the future, when

DOI: 10.54254/2755-2721/4/20230471

more methods are developed, review papers concluding methods analyzing dynamic movements will be considered to written.

**References**

[1] Liao, Y., Vakanski, A., Xian, M., Paul, D., & Baker, R. (2020). A review of computational approaches for evaluation of rehabilitation exercises (Computers in biology and medicine) 119103687

[2] Zhi Y X and Lukasik M and Li M H and Dolatabadi E and Wang R H and Taati B 2017 Automatic detection of compensation during robotic stroke rehabilitation therapy (IEEE journal of translational engineering in health and medicine) 6 1-7

[3] Kidziński Ł and Yang B and Hicks J L and Rajagopal A and Delp S L and Schwartz M H 2020 Deep neural networks enable quantitative movement analysis using single-camera videos (Nature communications) 11(1) 1-10

[4] Escalona F and Martinez-Martin E and Cruz E and Cazorla M and Gomez-Donoso F 2020 EVA: EVAluating at-home rehabilitation exercises using augmented reality and low-cost sensors (Virtual Reality) 24(4) 567-581

[5] Machlin S R and Chevan J and Yu W W and Zodet M W 2011 Determinants of utilization and expenditures for episodes of ambulatory physical therapy among adults (Physical therapy) 91(7) 1018-1029

[6] Wang S C 2003 Interdisciplinary computing in Java programming (Springer Science & Business Media) Vol. 743

[7] Baptista R and Ghorbel E and Moissenet F and Aouada D and Douchet A and André M and Bouilland S 2019 Home self-training: Visual feedback for assisting physical activity for stroke survivors (Computer methods and programs in biomedicine) 176 111-120

[8] Nascimento L M S D and Bonfati L V and Freitas M L B and Mendes Junior J J A and Siqueira H V and Stevan S L 2020 Sensors and systems for physical rehabilitation and health monitoring—A review (Sensors) 20(15) 4063

[9] Turner C R and Fuggetta A and Lavazza L and Wolf A L and 1999 A conceptual basis for feature engineering (Journal of Systems and Software) 49(1) 3-15

[10] Tao L and Paiement A and Damen D and Mirmehdi M and Hannuna S and Camplani M and Craddock I 2016 A comparative study of pose representation and dynamics modelling for online motion quality assessment (Computer vision and image understanding) 148 136-152

[11] Li Y and Chai X and Chen X 2018 ScoringNet: Learning key fragment for action quality assessment with ranking loss in skilled sports (Asian Conference on Computer Vision) pp. 149-164

[12] Liao Y and Vakanski A and Xian M 2020 A deep learning framework for assessing physical rehabilitation exercises (IEEE Transactions on Neural Systems and Rehabilitation Engineering) 28(2) 468-477

[13] Bruce X B and Liu Y and Chan K C and Yang Q and Wang X 2021 Skeleton-based human action evaluation using graph convolutional network for monitoring Alzheimer's progression (Pattern Recognition) 119 108095

[14] Liang F Y and Zhong C H and Zhao X and Castro D L and Chen B and Gao F and Liao W H 2018 Online adaptive and lstm-based trajectory generation of lower limb exoskeletons for stroke rehabilitation (2018 IEEE International Conference on Robotics and Biomimetics) pp. 27-32

[15] Qiu Y et al. 2022 Pose-guided matching based on deep learning for assessing quality of action on rehabilitation training Biomedical Signal Processing and Control 72 103323