Tracking Rehabilitation Exercises Using Virtual Reality System

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Abstract. Virtual Reality (VR) has advanced tremendously over the past decade. As a result of this advancement, it is also being used in rehabilitation assessment, treatment, and research. Today, virtual reality systems allow recording physical motions and investigating them in a computer environment. Calculated measurements can later be analyzed statistically using additional methods. That may help to determine a person's health condition. We developed a VR application that uses HTC Vive trackers to record patients' movements and visualize them in a 3-dimensional computer environment. The recorded data were later analyzed using artificial intelligence methods such as Convolutional Neural Networks (CNN) and Random Forests (RF). To compare different classifiers, model accuracies are estimated and discussed in this article.

Keywords: Virtual Reality · Motion Tracking · Physiotherapy · Convolutional Neural Network · Random Forest

1 Introduction

In physiotherapy the analysis of human physical behaviour depends on the specific measurement methods. The Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool6 has been used frequently to evaluate the quality of primary diagnostic test accuracy studies, particularly for systematic reviews [2], [5]. Various treatment methods rely on this type of data. However, the analysis could show some variance in human physical behaviour as it depends on units of measured data, methods, physical tasks, physiotherapist experience, and even the patient's stability during an exercise. To extract relevant information from a full data set is a complicated task for scientists or data analysts. The main issue is a huge amount of various data, so called big data [3]. Deep-learning algorithms could be used to avoid information overload and extract only relevant information. This may lead to more accurate clinical predictions and timely decision-making [6]. On the other hand, leaving only decision-making mechanisms to a system may lead to controversy in healthcare. While improving decision-making algorithms, for the therapist it is also important to implement personal insights

and provide technical analysis. Therefore we propose a system that uses VR technology with the component HTC Vive Tracker together with artificial intelligence methods for the decision-making. This research includes data analysis and signal classification using Convolutional Neural Network and Random Forest methods.

2 System Setup

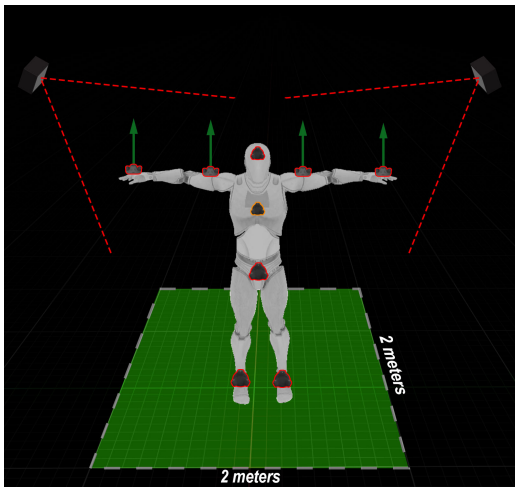

Fig. 1. Illustration of VR system setup

In this section the configuration of the human exercise tracking system that was used to perform the exercises is introduced. The developed exercise tracking system uses at least eight second-generation HTC Vive sensors. These sensors allow you to track the position in space and estimate rotation angles. The system also requires at least two HTC Vive stations (called base stations). However, it is recommended to use four base stations for constant connectivity to reduce the risk of missing data being recorded. The layout of the sensors is shown in Figure 1. The minimum space required for movement tracking is at least 2 square meters. A larger area should be allocated for convenience, but it must be ensured that there is no greater distance than 5 meters between base stations on opposite sides [1].

In this research a placement of different sensors and estimated rotation angles are important. There are eight sensors that are placed on the human body. The sensor layout details are:

- Two sensors are placed on the hands, pointing upwards,
- Two sensors are placed on the arm, pointing upwards,

– Two sensors are placed on the legs, pointing forward,
– One sensor is placed on the hips, pointing forward,
– One sensor is placed on the head, pointing forward.

After virtual reality equipment configuration, the application dedicated to a PC should be executed. At this point the system suggests the required actions for calibration. Once the calibration is over, the system is ready for use and data recording. In this paper a recorder signal consists of angle values that are estimated between two vectors.

3 Approach and Results

In total, eight physical rehabilitation exercises were selected. Eight healthy people participated in this experiment. Every person performed physical exercises five times. Every set of exercises consists of one correctly and two incorrectly performed movements. Physical motions were recorded during every exercise, and angles were estimated in each data frame.

For each exercise, there are three scenarios:

– correct motion(the user performs the given exercise with high accuracy);
– incorrect motion 1 (user performs the given exercise with one or more incorrect body part behavior);
– incorrect motion 2 (user performs the given exercise with one or more incorrect body part behavior).

Each scenario is recorded as a separate data set for each exercise. All data sets are combined and the classifier is trained using two different Artificial Intelligence algorithms - Convolutional Neural Networks and Random Forests, that are used to predict the correctness of the performed physical motion of a patient.

Exercise	Convolutional Networks	Random Forest
Hand reaching the nose	0,9086	1
Hand reaching on top of the head	0,6907	1
Arm bent from elbow and hands rolled	0,8319	0,86
Arm straight forward and hands rolled	0,8955	1
Arm sideways extended half way up and down	0,668	1
Picking up movement	0,7621	1
Arm straight, moving from side to up and forward	0,8669	1
Arm straight, full extended up and down	0,6689	1

4 Discussion

In this research, two artificial intelligence algorithms are used: CNN and RF [4]. For every exercise a separate model is constructed to classify correctly and incorrectly performed movements. The hyper parameter values optimisation is made

using random search technique. For the CNN model training, validation and testing the full signal of each movement is considered. Depending on what type of movement is performed, the different number of angles (signal leads) are analysed. Meanwhile, to construct the RF model three statistics are measured for every signal: average value, standard deviation and distance between minimum and maximum angle values. The obtained accuracies are presented in table 1. It could be noticed that Random Forests models are more precise for signal classification and in almost every exercise the 100% accuracy is reached. It should be noted that in this research incorrect movements were performed by healthy people and possible disabilities were simulated. Furthermore, CNN models usually are used with bigger data-sets. Meanwhile, experiments described in this paper consist of only eight people that may cause lower CNN model accuracies. Also, in this case, three classes of the data were considered (one correct and two incorrect movements) that could also affect the final result.

5 Conclusion

After comparison of two different AI algorithms it was noticed that RF classifiers are more accurate for correct and incorrect movement recognition. Eight different exercises were analysed and in most of the cases, the RF model reached even 100% accuracy. In the experiments that are described in this paper only healthy people participated and incorrectly performed movements were simulated. This could have a significant impact on final results and model accuracy. Future experiments should include real patients that have motor disorders.

References

1. Borrego, A., Latorre, J., Alcañiz, M., Llorens, R.: Comparison of Oculus Rift and HTC Vive: Feasibility for Virtual Reality-Based Exploration, Navigation, Exergaming, and Rehabilitation. Games for Health Journal **7**(3), 151–156 (2018). https://doi.org/10.1089/g4h.2017.0114
2. Cook, C., Mabry, L., Reiman, M.P., Hegedus, E.J.: Best tests/clinical findings for screening and diagnosis of patellofemoral pain syndrome: A systematic review. Physiotherapy **98**(2), 93–100 (2012). https://doi.org/10.1016/j.physio.2011.09.001, http://dx.doi.org/10.1016/j.physio.2011.09.001
3. Keim, D.A., Mansmann, F., Schneidewind, J., Ziegler, H.: Challenges in visual data analysis. Proceedings of the International Conference on Information Visualisation pp. 9–14 (2006). https://doi.org/10.1109/IV.2006.31
4. Pavlov, Y.L.: Random forests. Random Forests pp. 1–122 (2019). https://doi.org/10.1201/9780429469275-8
5. Whiting, P., Rutjes, A.W., Reitsma, J.B., Bossuyt, P.M., Kleijnen, J.: The development of QUADAS: A tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. BMC Medical Research Methodology **3**, 1–13 (2003). https://doi.org/10.1186/1471-2288-3-25
6. Yu, K.H., Beam, A.L., Kohane, I.S.: Artificial intelligence in healthcare. Nature Biomedical Engineering **2**(10), 719–731 (2018). https://doi.org/10.1038/s41551-018-0305-z, http://dx.doi.org/10.1038/s41551-018-0305-z