BABEȘ-BOLYAI UNIVERSITY
FACULTY OF MATHEMATICS AND COMPUTER SCIENCE

SUMMARY OF THE DOCTORAL THESIS

Intelligent Rehabilitation Systems Using Motion Camera Interaction

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Thesis Summary

1.1 Intelligent Rehabilitation Systems Using Motion Sensors

1.1.1 Introduction

This research aims to explore the potential of artificial intelligence for interactive rehabilitation systems based on video games and motion cameras, which are currently used in clinical practice. With a vast application in physical and cognitive therapy, these systems provide a more personalised and accessible way of rehabilitation, revolutionising healthcare delivery and improving clinical outcomes, for a better quality of life.

In our work, we focused on obtaining better user experience personalisation, utilising the motion data from the 3D camera (in our case, the Microsoft Kinect and Orbbec sensors), not only from the exercise movements for physical therapy, but also from the indirect input which arises while interacting with the system: body language, actions, and other user states and emotions which are expressed through gestures.

With this in mind, we have concentrated our research around two important topics: the first is improving gesture recognition and the second is enhancing user experience. Intelligent gesture recognition was performed based on the 3D skeleton data streaming from motion sensors like the Microsoft Kinect. For this, several machine learning techniques were used to classify postures and time series gestures. Furthermore, we have proposed a method to improve the performance of these algorithms when used with certain time series multi-joint gestures. In what concerns user experience, our aim was to apply dynamic game difficulty balancing concepts adapted to elderly people, which constitute a relevant category of end-users of interactive rehabilitation systems.

Based on the results, a system can analyse movements performed by the user and generate feedback regarding the correctness of their exercise and how it can be improved, acting like a virtual intelligent assistant. Moreover, it can adjust visual and other sensory aspects of the virtual environment, according to the indirect gestural input, modifying game settings for an optimal user experience of the exergames.

These results were destined to be applied to systems for active ageing, especially the MIRA platform – a medical software containing cognitive and physical exergames for the rehabilitation of several patient groups, including children and older people [Can+17].

1.1.2 Pose and gesture recognition

We have commenced our work by analyzing several machine learning techniques to classify poses and gestures recorded with Kinect 1 and Kinect 2 sensors, in the form of skeleton data. We have compared the way the classifiers' performance (accuracy, precision, time to build the model) is influenced by factors like sensor input accuracy (referring to the improved hardware of Kinect 2 in comparison to Kinect 1), data interpretation (referring to the number of classes contained by the dataset to classify), and sample data size (referring to the number of joints considered for a pose sample).

Therefore, we aimed to make use of these results to help decide for a particular type of gesture recognition system which sensor is best to use, but also which combination of algorithms and way of interpreting data will yield the best outcomes. Furthermore, we have approached in our research several methods for improving movement analysis and accuracy of gesture recognition, besides some practical approaches to integrate the user input and utilize motion analysis to drive personalisation in the interaction of the user with rehabilitation systems (namely MIRA). Algorithms used in our experiments are based on the implementations from the Weka [Hal+09] and GRT [GKO11] libraries.

The original contribution in this research area consists of creating several databases of meaningful poses and gestures using sensors Kinect 1 and Kinect 2, and comparing the results and efficiency of several classifiers. For this we have analysed the sensor type and gesture complexity, as well as the data size and characteristics for both poses and gestures which influence the accuracy of the results. Of these, special attention is given to comparing HMM and DTW for time-series gesture recognition.

1.1.3 Motion analysis

Another important contribution is proposing a new method for motion analysis which separates different movement components (pose, movement amplitude and movement main trajectory), separating active and passive joints, in order to improve gesture recognition and extract information on movement correctness. Tested on our database and existing Kinect benchmarks, this method improves the accuracy obtained with previously used algorithms (DTW, HMM) and enhances our motion analysis model.

1.1.4 Dynamic game balancing

In the area of dynamic game difficulty balancing, we propose a new emotional-motivational game balancing model tailored for active ageing game systems based on indirect input derived from postures or gestures of the user. This model focuses on adjusting the UI or difficulty features according to the user performance, considering the particularities of players from the elder people group.

1.2 Thesis contents and main results

This work is structured into seven chapters, as follows:

- **Chapter 1**: We introduce the thesis topic and main areas of application in rehabilitation [Mol+14; Mol+17] of existing eHealth systems, namely MIRA [Can+17].
- **Chapter 2**: We present the state-of-the-art on gesture recognition and motion analysis for physical therapy, focusing on the use of motion sensors, especially Microsoft Kinect [Mic17], but also other 3D cameras which are currently widely used.
- **Chapter 3**: This chapter presents our original contribution in pose recognition, for which we have obtained several promising results published in [Căl16a; Căl16d; CC18]. We found that Kinect 2 has a great potential in improving overall accuracy and precision of most of the classifiers we considered, comparing it with Kinect 1. On the downside, it also

implies more complex and time consuming computations. Thus, Kinect 2 is preferable, but it is not yet proved to constitute a universal best option for gesture recognition systems, as there are classifiers that give results on Kinect 1 data which are close to the best obtained with Kinect 2, requiring a significantly reduced computation time. For example, the best accuracy is with Simple Logistic (98.20%) on Kinect 1, a close value to the best accuracy on Kinect 2 with Multilayer Perceptron of 99.08% (with 5.54s, respectively 65.93s time required to build the model).

We also found that some classifiers (for example Hoeffding Tree, Bagging, Naive Bayes or Naive Bayes Updateable) improve their accuracy when class specificity and the number of classes are increased, where applicable.

- **Chapter 4**: In this chapter, the original contribution is presented in the approach towards the classification of time-series gestures. The results published in [Căl16c] were very promising for both sensors (up to 97.85%). They show that there is a good potential in time series gesture recognition classifiers for recognising complex one-hand gestures, such as shapes of letters or digits.

  When we compared the performance of the two algorithms depending on database size, we discovered that DTW performs better with fewer entries per class (a drop in accuracy from 97.80% to 66.6%, when we increased the number of entries per class). In what concerns HMM, the algorithm yielded a similar or higher accuracy when we increased the number of samples per class. The best overall result was obtained by DTW (97.80% on Kinect 1), whereas the highest value for HMM was a bit lower (96.35% on Kinect 2). Still, DTW is dependent on the database size, which, if increased too much, will negatively affect its performance. This makes HMM preferable for gesture recognition in systems that are dynamically created and adjusted, while DTW might be a better option for static systems, in which the number of samples is previously established and there is a non-modifiable set of the gestures we want to classify.

- **Chapter 5**: Moving forward, this chapter presents an original contribution in motion analysis, proposing a method to increase accuracy for the classification of multi-joint complex gestures. A better classification accuracy was obtained after applying our method, with improvements of up to 56% for HMM and up to 32% for DTW, respectively. Furthermore, a positive correlation between movement amplitude and the EF feature was found (r=0.92), a result from which we can easily derive user feedback to help patients improve on the physical performance of an exercise. The proposed model and the results obtained have been presented in [CPB17].

- **Chapter 6**: This chapter describes our original contribution regarding dynamic game difficulty balancing and the way in which we are able to use indirect motion input from the users to personalise their interaction. Based on these results we look into a practical application for game difficulty balancing in active ageing systems for elderly people, proposing a tailored model presented in [Căl16b]. The second part of this chapter features clinical implications outlined by independent researchers from the academic and medical field [STS15; Sta+16; Mol+17].

- **Chapter 7**: In this chapter we draw the main conclusions of our research and specify the most relevant directions and potential improvements that we propose as future work.

1.2.1 Table of contents

In the following we present the detailed structure of the thesis:

1.3 The importance of this research and main conclusions

In this thesis we have explored the use of Kinect and machine learning methods for gesture recognition and motion analysis, obtaining results that are reliable to be explored further for use in practice (over 90% accuracy for pose and gesture recognition). Ultimately, we aim to construct an intelligent virtual assistant that is able to provide adequate feedback to patients using home-based rehabilitation systems on how to improve their movement performance.

All these research findings have been aimed to support and improve existing commercial rehabilitation systems, such as MIRA, which is used in over 70 clinical institutions across 7 countries. Its impact in enhancing the experience of rehabilitation therapy and its outcomes and other benefits have been quantified by collaborating partners from the rehabilitation domain and independent clinical researchers [STS15; Sta+16; Mol+17] in feasibility studies and randomised controlled trials.

There are several other potential directions to make use of our research findings, extending to other systems which use motion cameras for interaction. Furthermore, recognising user states or emotions, gesture prediction or gesture generation are some of the other topics of high interest as future work.

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