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Serious Gaming and AI Supporting Treatment in Rheumatoid Arthritis

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Abstract. This paper presents a complex application for rehabilitation of patients with first and second stage rheumatoid arthritis (RA). The application contains a module for the doctor, for the kinetotherapist, and a module as a game matching the symptoms for each stage of RA. The purpose of this application is to achieve the rehabilitation of the RA hand with support of digital technology and multimodal interaction: leap motion, serious gaming, and neuronal networks. The neural network offers support for patients to perform the exercises at home classifying the correct movement with accuracy of 95%. During the development of the application, various challenges were encountered in terms of populating the database, raising the cubes within the game related to second stage of RA, and the implementation of the neural network. The application was tested by a group of students, resulting in the fact that the degree of mental stress, fatigue in the fingers, wrists and physical exertion were insignificant in most cases.

Keywords: virtual reality, hand rehabilitation, leap motion, rheumatoid arthritis, machine learning, serious gaming, multimodal interaction

1. Introduction

Rheumatoid arthritis (RA) is an autoimmune systemic disease of inflammatory nature with a severe prognosis that affects the daily activity, quality of life and decreases life expectancy more and more in recent years. This condition affects both sexes, to a greater extent woman (3: 1), but the disease affect in same proportion beyond 50. It is more common in people between the ages of 40 and 60. The cause of RA is not exactly known, assuming it is due to several genetic, environmental, and immune factors. RA is defined by arthritis of an inflammatory nature in the diarthrodial joints and most often in the small joints of the hand, as can be seen in figure 1. Large joints are later affected [1].

Through games and technology, patients are more involved in performing exercises, better results are achieved, and rehabilitation is more efficient. These games can be an assisted therapy for the patient, who can practice anytime and anywhere.

From recent literature, it follows that there has been an improvement in reactions, in self-esteem and emotional well-being.[2]

Leap Motion device can be, also, used for education "providing a better understanding of healthcare related subjects for both medical students and physicians"[3] and for gesture classification using neuronal network [4] "The results confirmed that the

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gamification of classical medical software provides an increased interactivity level for medical students during the study of the human skeleton" [4].

Figure 1. Normal and RA hand

1.1 Market research

Currently there are various sensor devices for movement therapy, hand, grip measurement, VR gloves and others. The most advanced device is a manual exoskeleton that measures the angles and forces of the joints. However, it is considered that the devices are not accurate enough because differences in measurements are noticed. One of the most suitable devices that tracks the movement of fingers and hands is Leap Motion [5].

ArthriKin is an application that monitors the exercises performed by the patient and provides real-time feedback and corrections when notified. Motion detection is monitored with Microsoft Kinect device to record body posture during daily exercises [6]. Another application supports occupational hand therapy, following the estimation of joint movement angles and a skeleton that estimates the 3D positions of the hands using a neural network.[7] Another experimental study shows that virtual reality in Leap Motion recovery contributes to a significant improvement in dexterity, flexion, extension, and ulnar deviation [8]. Table 1 shows a comparation of existing applications / studies.

Table 1 Comparison of applications

Application	Kinect	Leap Motion	Other equipment	Neuronal Network	Gamification
ArthriKin	x				
Framework for dynamic evaluation			x	x	
Experimental VR training		x			x

In conclusion, currently, the existing applications use both, Microsoft Kinect, and Leap Motion, for hand rehabilitation. It is also noted the use of the neural network and gamification.

In this paper we present the Virtual Arthritis Rehabilitation application. The purpose of this application is to achieve the rehabilitation of the rheumatoid arthritis hand with the help of leap motion technology through games associated with 2 stages of this disease.

The objectives of this paper are: to demonstrate the effectiveness of the leap motion device in the rehabilitation program, to streamline kinetotherapy treatment for patients with rheumatoid arthritis, and to monitor the process of making appropriate and attractive games for patients with rheumatoid arthritis.

2. Methods

The technologies for the development of the Virtual arthritis rehabilitation application are based on the Visual Studio environment, version 2019, using C# language. The interface is simple, so that the doctor and therapist can use it as easily as possible. This aspect is outlined by an intuitive menu (e.g. File->Add new patient, delete patient). Therefore, the doctor, can register and authenticate. It will also be able to add a new patient, modify existing data, delete, search for a patient, and view current and deleted patients. The connection between the application modules is shown in figure 2. The kinetotherapist has the possibility to visualize the doctor's patient data input, search for a specific patient by various categories (e.g. name, surname, diagnosis, etc.), and to start the game according to the RA stage. Both applications have the help option, with information on how the application works.

The games are developed on the Unity platform. For first stage of RA the game will allow flexion and extension of the wrist, and in the game this means to maintain a character above a field and pass it through several rings (Figure 3). Earning points is achieved by going through as many rings as possible. If the character falls, the game ends. It is recommended to obtain a minimum score, to encourage the patient to go through as many rings as possible. The patient can pause the game, leave the game at any time and get help at the beginning. If the patient has second stage RA, the game will allow him to travel a path with the help of a character and navigation keys. After, he traveled the path, will reach a house, will enter, and the character will disappear, but the patient's hands will appear after connecting the Leap Motion device in order to use her/him hands to put the cubes in the box. The patient will have to put cubes in the box, and if he succeeds, a special effect of red cubes will appear, as seen in figure 4. With each cube placed in the box, the score will increase. A problem encountered during implementation was that the hand controller lifted all the objects at once, and not one at a time. To fix this issue, the object placed in the box is disappearing and instead of that another appears.

As the patient was encouraged to practice recovery exercises at home, machine learning was introduced to guide the health professional and the patient through the best exercise for the patient, consolidating the idea of personalized therapy. The neural network has as input the distance between the thumb and the index finger, the distance between the thumb and the cube, the distance between the index finger and the cube, the speed of the cube when it is placed in the box, the time used to put the cube in the box, the distance between the cube and box, and the obtained score. While the patient is playing, a message will appear at some point and the game will pause until the movements are evaluated (figure 5). If the movements are performed correctly - the accuracy in detection of hand gesture/exercises of neuronal network is greater than 90% - the cube is replaced by a narrower 3d model than the cube (figure 6). In this way the exercise/game is tailored by the better or worse performance of the patient. The patient can perform finer exercises, and this guides her/him to fully recover. In the case of both games, at the end, a message will be displayed as feedback with recommendations. The script for the neural network is written in Python, version 3.7, using the following libraries: *pandas, tensorflow, numpy, keras, sklearn*.

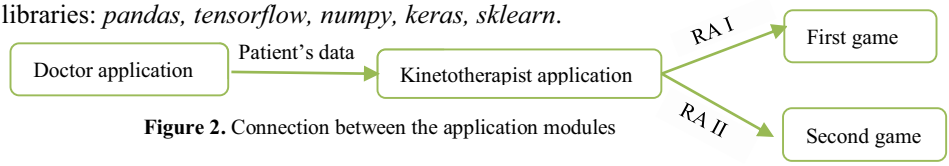

Figure 2. Connection between the application modules

Figure 3. Game for RA stage I

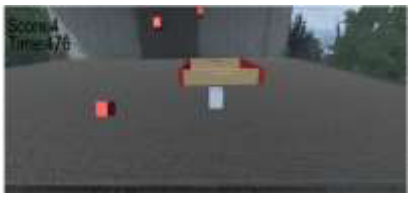

Figure 4. Game for RA stage II

Figure 5. Movement evaluation

Figure 6. Results, after movement evaluation

3. Results

The paper focused on the development elements of serious gaming applications in support of RA treatment and emphasizes the benefits of personalized care and highlighted several elements that presented implementation challenges and are useful for software developers.

With the popularity of the database in Unity, due to the large number of fields required to add a patient, a clear view of each was difficult. It was decided to use Firebase and visual studio and integrate the games in this environment.

Another problem was when lifting the cubes with the help of the Leap Motion device, the method by which the finger used was checked figured as an error. It turned out that introducing the necessary leap motion OVR packages would solve this error.

Regarding the introduction of the neural network in Unity, it was initially decided to use a coroutine called in Update() function. After testing the functionality, it turned out that the routine was called only once, and the code was not executed every time at the right time. To fix this issue was created a function that returns accuracy and called it after all the data has been saved in the csv files. Another problem encountered was that 20% of the training data was initially used as test data, and this aspect led to errors in terms of the result. An analysis of the data saved in the csv file was made. The values used as input were adjusted, more data was entered, and training data was separated from the test data.

To validate the performance of the neural network, the following metrics were calculated: accuracy, precision, F1 score and recall. The following values were achieved: for 95% accuracy and precision, f1 score: 97% and for 100% recall.

Currently, the application was tested by a group of 7 students, following the degree of mental stress, fatigue in the fingers and wrists and physical exertion. The following results were achieved: the fatigue of the fingers was small, respectively too small in most cases. The mental effort made by the user was in 57% of cases too small, 14% medium, 14% high and 15% low. The physical effort required by the user was in most cases a small one, few of them stating that it would be a small one, respectively medium. Regarding the fatigue of wrist, it was in 67% of cases small, 16% too small, and 17% medium. Most of the users were unexperienced in using the leap motion device, showing interest, and giving positive impressions.

4. Discussion

Patients with rheumatoid arthritis have joint stiffness, pain in the flexion of the fingers, decreased muscle strength, muscle contractions that contribute to flexion, but early recovery can contribute to significant improvement.

Current research confirms that the rehabilitation through technology, virtual reality and games contributes significantly to reducing symptoms and treating the disease. The Leap Motion device is considered one of the most suitable for the rehabilitation of hand diseases because it has such a high accuracy that, we cannot achieve.

In the current context, such an application would be useful for both, patients and medical staff. Thus, better results are obtained, progress would be more visible in terms of recovery, and patients could have feedback through the machine learning algorithm from the comfort of their home. The accuracy in the detection of recovery gestures being very high, over 95%, offers consistency on the feedback provided by the application through the help of machine learning techniques.

As future developments, we will work to introduction of various specific reports for the attending physician and therapist, and develop a neural network for the game related to the first stage of RA. The work is supervised by colleagues from the Balneophysiotherapy Clinic, Medical Recovery and Rheumatology of Timisoara, and in the next step we will report the results of the evaluation of the application with RA patients.

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