Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. **66**, *3*, pp. 189–193, Bucarest, 2021

Génie biomédicale

ADVANTAGES OF TELEMEDICINE IN NEUROREHABILITATION AND QUALITY OF LIFE IMPROVEMENT

IULIA-CRISTINA STANICA[1], FLORICA MOLDOVEANU[1], MARIA-IULIANA DASCALU[1], IOSIF VASILE NEMOIANU[1], GIOVANNI-PAUL PORTELLI[2]

Key words: Telemedicine, Telerehabilitation, Neurorehabilitation, Virtual reality, Assistive technology.

This paper focuses on researching the potential of telerehabilitation for improving the quality of life of patients. As telemedicine is gaining more and more ground in various medical fields, its application in neurorehabilitation can reduce costs, improve the training process, facilitate the communication between patients and therapists, as well as ensure the supervision of the rehabilitation progress through technology means. After analyzing the existing studies related to telemedicine in neurorehabilitation, we draw the line to show the advantages and drawbacks of the process. We then present our current work, the INREX-VR project for neurorehabilitation, which has the goal of helping people recover easier from neurological disorders with the help of virtual reality, motion detection, biosensors and telerehabilitation.

1. INTRODUCTION

Nowadays, the advancement of life expectancy thanks to the endless progress of medicine [1] contributes to the worldwide phenomenon of population ageing. Subsequently, the increase of life expectancy emphasizes the importance of physicians in people's life and the need of continuous progress in the medical field, where technology becomes ever more important [2–5]. The increase of the median age does not come only with advantages, as a longer life is not synonymous with a qualitative life. Numerous neurological disorders have a significant higher prevalence in elderly people [6], therefore adequate rehabilitation procedures and rehabilitation specialists become indispensable in today's society.

Unfortunately, the resources in the field of rehabilitation are insufficient when compared to the people's needs. As stated by the World Health Organization, "74 % of years lived with disability" can be improved with the help of rehabilitation [7]. Yet, the workforce in terms of physicians, nurses and therapists is low while the demand for rehabilitation increases.

One possible solution for the insufficiency of medical personnel in the field of rehabilitation can come from telemedicine – and more precisely, its subsequent domain of telerehabilitation. As telemedicine refers to remote medical services, it does not require physical presence of the patient in the therapist's office. Telerehabilitation can therefore resolve issues related to the lack of a sufficient number of therapists, problems in availability and access to medical services, problems of schedule and appointments synchronization.

Our current paper has the purpose of analyzing existing systems which use telemedicine in the field of neurorehabilitation, in order to understand their advantages and drawbacks. In the following chapter, we will focus on defining terms such as telemedicine, telehealth or telerehabilitation, as well as identifying their main advantages and disadvantages. In the third chapter we are going to present a short review of the current state-of-the-art regarding the use of telerehabilitation in modern systems (either from research studies or in clinical use). Finally, the fourth chapter includes the presentation of our own approach to telemedicine through the INREX-VR neurorehabilitation project and the fifth chapter draws the conclusions of our research.

2. TELEMEDICINE – CONCEPT, HISTORY, ADVANTAGES AND DRAWBACKS

According to the World Health Organization (WHO), telemedicine, the so-called "healing at a distance" [8], refers to the use of information and communications technology (ICT) to deliver health care services from a distance. This includes diagnosis, treatment, surveillance, evaluation, education and so on [9]. The concept is often referred to as e-medicine, e-health or telehealth [10].

History of telemedicine dates as far back as the beginning of the twentieth century, with reports stating the use of telephone wires for transmitting electrocardiography data [11]. After the rise of computers, the interest shifted from synchronous means of communications to digital storage methods. With the advent of the Internet and technology evolution, telemedicine embraces the use of asynchronous communication means (*e.g.*, text messages, emails), real-time video and audio calls, cloud services and so on [12]. Nowadays, smartphones and social media have become mandatory aspects in day-to-day life, being therefore facilitators for providing e-health services. The first specialty which benefitted from telemedicine is radiology, dating as far back as the 1950s [13]; it is also the most widespread specialty worldwide in terms of telehealth, a survey by WHO showing that it is present in 33 % of the 114 countries participating in the study [9].

Telemedicine has appeared as a solution for some difficulties encountered in classical medical services. The advantages of telemedicine include:

- Accessibility – services can become available for people all around the world, regardless of their geographical position, urban or rural, essential aspect

[1] University POLITEHNICA of Bucharest, Splaiul Independentei 313, Bucharest, Romania; E-mails: iulia.stanica@upb.ro, maria.dascalu@upb.ro, florica.moldoveanu@cs.pub.ro, iosif.nemoianu@upb.ro
[2] "Carol Davila" University of Medicine and Pharmacy, Department 4, Eroii Sanitari 8, Bucharest, Romania, giovanni.portelli@drd.umfcd.ro

for underdeveloped countries or regions.

- Time and distance convenience – no time spent for traveling to the physician's office, no distance traveled (great facilitator for people in certain health conditions, such as post-operative care).
- Lower costs – expenses are reduced as people do not need to travel to be physically present in the physician's office; some telemedicine systems can have lower costs than real-life appointments.
- Communication and scheduling – better flexibility for appointments for both patients and health providers, which reduces cancellations.
- Permanent supervision – for specialties that require constant training (*e.g.*, physical or mental rehabilitation), the physicians can use telemedicine means to permanently monitor and evaluate the patients' progress;
- Increased motivation for training and preventive care – the constant awareness that the training progress and health condition are permanently monitored by physicians can motivate and encourage people to train constantly, respect medical indications and take better lifestyle choices.
- Decreased spread of diseases – as there is no need to be present in a hospital, people that benefit from the use of telemedicine are less likely to contract infections; this advantage can be crucial especially for people with a compromised immune system [14].

There are however some drawbacks which come mostly from the use of technology or the lack of physical interaction. These include:

- Security risks – they come inevitably with the use of technology, and patient data can become the target of security breaches.
- Lack of suitability for non-technical patients – this drawback becomes less present as people of all ages tend to become familiarized with technology; more complicated systems can however prove a challenge for people not familiar with technology.
- Special technical training needed for medical personnel – similarly, not all health care providers know how to use various ICT systems, especially those in underdeveloped countries or rural regions.
- Emergency care not always possible – telemedicine not suitable for care in life-threatening situations, if the system is not monitoring in real-time data from biological sensors or panic/emergency signals.
- Weaker patient examination – in telemedicine, healthcare providers must listen to their patients describing their symptoms and health condition; this can be less efficient and accurate when compared to face-to-face examination;
- Impossibility to provide medication prescriptions – in some countries, providing online medical prescriptions is prohibited without physical examination [10] – mostly a regulation issue, not directly influenced by telemedicine as a technology.

If put in balance, the advantages outweigh the disadvantages. Most of the technical drawbacks can be overcome with special training for both providers and patients and stronger security for the software systems. Some aspects of medical care (patient examination, emergency care, medication prescription) cannot be replaced by telemedicine, so classical medical procedures and ICT-based ones must be combined for the best outcome.

3. TELEREHABILITATION – APPLICATIONS FOR NEUROLOGICAL DISORDERS

Telerehabilitation (or e-rehabilitation) is a subfield of telemedicine which refers to methods used for monitoring the rehabilitation process "at a distance" [15]. It refers to both psychological and physiological rehabilitation, yet our focus is on neurorehabilitation, as it is the main goal of our virtual reality (VR) system.

Researches show that there has been an increased interest in the field of telerehabilitation [16], especially due to recent technological advancements. Robotic devices and virtual reality are some of the most used technologies for neurological telerehabilitation [17]. One such example is Rehab@Home, a telerehabilitation system for improving or recovering motor functions. Based on commercially available hardware devices (Microsoft Kinect and Wii), the system includes two software applications: one for patients, with specific gamified exercises, and the second one for therapists, for monitoring and configuring the difficulty of the training sessions. Final reports of the project show that it was received positively by both patients and therapists, and that there have been significant improvements in functional abilities after multiple rehabilitation sessions [18]. Another home-based system using virtual reality is developed for lower-limb rehabilitation of people with spinal cord injuries. Using special sensors attached to lower limbs, the patients' movements are displayed in various virtual scenes created using Unity 3D game engine. The exercises are designed to train all lower limb joints, using simple or complex movements, but all in gamified settings. The outcomes show that the system was well received for training at home, and the patients improved various characteristics of their lower limbs, including strength, mobility and balance [19].

As a relatively recent field, telerehabilitation proves successful in numerous research studies [20], yet does not often extend to commercial level because of skepticism and lack of affordable devices. Nevertheless, since virtual reality hardware devices become more and more accessible today, they can prove to be a viable alternative, less expensive and more convenient than previously used robotic devices. In the following chapter we will thus present our VR system for telerehabilitation as an application for people suffering from neurological disorders.

4. INREX-VR PROJECT

INREX-VR (Immersive Neurorehabilitation Exercises Using Virtual Reality) is a complex system which uses the advantages of virtual reality and telemedicine for improving the neurorehabilitation process of different neurological disorders, including, but not being limited to, cerebrovascular affections, Parkinson's disease, disorders of the central and peripheral nervous system [21]. INREX-VR has the goal of facilitating training in the field of neurorehabilitation for both sufferers and medical personnel (medicine students, nurses, interns, therapists and so on).

Most of the technical aspects of the INREX-VR system are the focus of previously published papers [4, 21]. Nonetheless, for reader's convenience and to make our presentation self-contained, we briefly outline the technical solutions adopted for implementing our proposed system, as well as testing results that quantify the efficiency of the platform.

The central system consists of a software application developed using Unity3D game engine and including a great variety of gamified exercises for neurorehabilitation, which take place in different virtual scenes. Exercises are divided into two main categories (tutorial exercises and games) and have the goal of helping people improve affected functionalities for both upper and lower limbs. Tutorial exercises have the role of helping people get used with the system and present a series of classical rehabilitation exercises performed by a virtual therapist which must be imitated by the user. The games category is more complex, combining multiple movements trained in the tutorial category, and emphasizing more the entertainment factor. Both tutorial and games categories are summarized in Table 1. All virtual scenes include gamification elements (challenges, rewards) to keep people motivated to continue the training process.

Table 1

INREX-VR system - Neurorehabilitation exercises

Exercise	Short description
Lower limb	
Ankle flexion-extension	*Exercise that requires an angle of 45 degrees for the ankle joint*
Knee flexion	*Exercise that requires an angle of 75 degrees for the knee joint*
Hip flexion	*Exercise that requires an angle of 90 degrees for the hip joint (front movement)*
Hip abduction	*Exercise that requires an angle of 45 degrees for the hip joint (side movement)*
Football game	*Game where the user must shoot the ball to hit the goal from a fixed position*
Dancing game	*Arcade dancing game, the user must step on glowing squares on the floor, according to the music's tempo*
Upper limb	
Fist extension	*Exercise that requires an angle of 50 degrees for the fist joint (front movement)*
Fist adduction	*Exercise that requires an angle of 70 degrees for the fist joint (side movement)*
Forearm extension	*Exercise that requires an angle of 145 degrees for the elbow joint (front movement)*
Forearm pronation	*Exercise that requires an angle of 90 degrees for the elbow joint (circular movement)*
Arm pushing	*Exercise that trains both elbow and fist joints, through a "wall pushing" move*
Shoulder extension	*Exercise for the shoulder joint, 0-90 degrees or 90-180 degrees (bringing arm in front or raising it above head)*
Shoulder abduction	*Same requirements as for the previous exercise, but movement to the side*
Spinning wheel	*Specific Parkinson's disease exercise which tests hands' coordination*
Boxing game	*Different boxing techniques are trained (guard, jab, cross punch, uppercut), without any physical resistance*
Hitting targets game	*A ball must be picked up and thrown to hit a tower of cans*
Ball directing game	*A ball must be directed on a table in order to land in some holes situated at its end*
Whack-a-mole	*Classical arcade game, the user must hit the moles using a hammer in 60 seconds*

The hardware components consist first and foremost of an HTC Vive Cosmos Elite system, with a head mounted display (HMD), two hand controllers and two trackers attached to the feet. This is the core of the virtual reality part of the INREX-VR project (Fig. 1) and ensures both the immersion of the user in the virtual environments and the real-time detection of movements. For creating the real time animations of both the therapist and the user's avatar, we combined the HTC Vive sensors with inverse kinematics (IK) principles, with the help of the Animation Rigging Unity package. By using a detailed 3D model with the appropriate skeleton hierarchy, we map each sensor to the

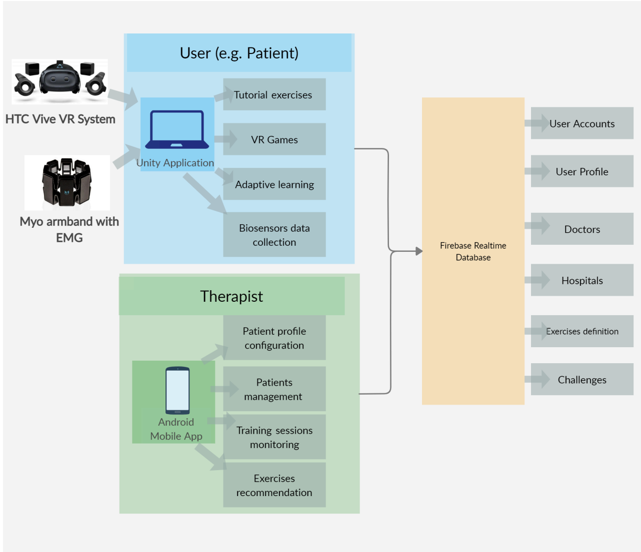

Fig. 1 – Proposed system schematic.

appropriate end effector (hand wrist or ankle) and approximate the middle (elbow or knee) and upper (shoulder or hip) joint angles through IK [21]. The results are satisfying and can be improved if the limb measurements of the avatar are configured to match the proportions of the patient. This requires either custom 3D modeling of the avatar or the creation of a parameterizable model whose limb segments can be scaled accordingly in Unity. These improvements will be taken into account in future upgrades of the INREX-VR system, as for the moment the exercise evaluation works correctly with the standard avatar measurements, even if the angles might differ with a few degrees. In addition, a Myo Gesture Control Armband is attached to the forearm, which includes electromyography (EMG) sensors integrated for analyzing the upper limb's muscle activity. Other devices, which are used during testing, include smart watches or smart bracelets for monitoring permanently the health parameters (heart rate, effort level, oxygen saturation and so on). As presented in [4], data collected from the Myo armband has multiple uses in terms of neurorehabilitation and, in particular, in the development of our system. The bracelet contains inertial measurement units on nine axis which allow the evaluation of position, rotation and acceleration. Since this data is similar to the one provided by the HTC Vive trackers, Myo armband comes as a great alternative for the use of a lighter, non-VR version of the system, where the hand controllers are replaced by the bracelet. By being capable of recognizing predefined gestures, Myo was successfully used in tests as input device for the upper limb games, providing also haptic feedback. The EMG data was visualized using a Matlab SDK and can be further analyzed by specialists, in order to identify the muscle activity or its affection during several basic tasks (picking up objects, lifting the arm, squeezing the fist, *etc.*).

As much as gamification counts towards motivation, constant supervision and guidance are needed in the field of neurorehabilitation. The system focuses therefore on allowing therapists to configure and to have access to their patients' training process, as it is performed in the INREX-VR setting. The telemedicine feature consists of a central Firebase Realtime Database with which both the Unity application, used by the patient, and an Android mobile application, used by the therapist, can communicate (Fig. 1). The database is functioning on No-SQL principles with the information structured using JavaScript Object Notation (JSON) files. Data is synchronized in real-time on all devices, allowing thus a smooth monitoring process of the training sessions. Only authenticated users have access to reading or writing data in the database, as set by specific Firebase security rules. Therefore, doctors can only access their patients' information, a patient can only view their doctor's recommendations (without editing them) and can send data specific only to their own training session.

The Unity application communicates through a specific REST client [22] with Firebase, saving data related to each training session performed by the user (tutorial or game session, date, duration, number of repetitions executed, evaluation or game score) or related to the user's health data (EMG). This data is displayed then on the therapist's mobile application, as a "history" of their respective patient's training process. Each patient can access their profile to see which exercises have been recommended by the therapist, and these recommendations will automatically influence parameters during the VR training sessions (such as starting difficulty, number of repetitions).

Each therapist can connect to the database using an easy-to-use Android application. After creating an account or logging in, they can visualize their patients or add new ones. For each patient, the therapist can view the history of their training sessions, recommend exercises (of type tutorial or game, Fig. 2), edit their profile (disorders, current treatment) and view or remove the exercises that they already recommended. Adding a new exercise as a recommendation (Fig. 2b), but with new configured parameters than the one saved in the database (including here the body side of the exercise – left, right or both –, the frequency of execution – daily, two times a week, weekly or monthly –, the number of repetitions or the recommended starting difficulty), will replace the previously added exercise of the same type.

Patients will always have access only to the most recent recommendations of their therapist. The recommended starting difficulty is available only for games and has the goal of being a "starting point" for the adaptive learning

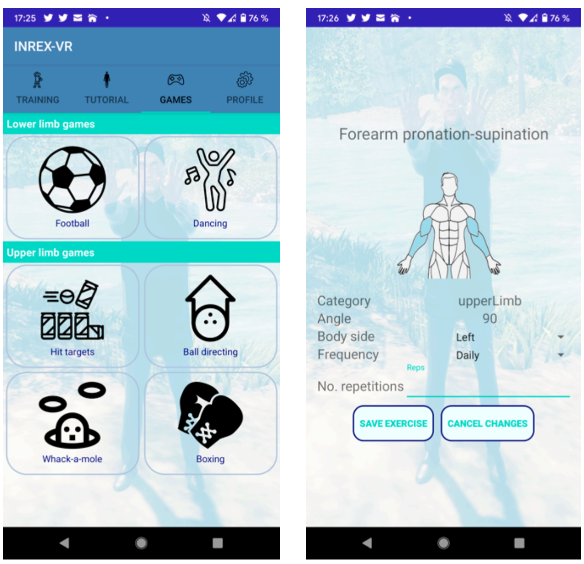

Fig. 2 – Mobile application for therapist surveillance: games list (left); details for tutorial exercise configuration (right).

algorithm integrated in the Unity application. Therefore, the exercise will start at the difficulty recommended by the therapist and will further adapt automatically based on the user's performance.

The validation of the system consisted in several testing stages. After a preliminary training session with a Parkinson suspect who is also a physician, including the hitting targets game [4], the other games and exercises have been developed or changed according to their feedback. Therefore, the focus was moved from evaluating the performance based on the execution time to the one based on the number of repetitions, since neuroplasticity is stimulated by the repeated execution of the same task. In order to avoid boredom, gamification elements became a significant part of the system, including real-time dynamic difficulty adjustment. Further tests included a thorough laboratory study with 8 subjects based on a testing procedure created in collaboration with medical specialists. The testing procedure included 4 stages (accommodation, tutorials, games, final feedback) and focused on both upper and lower limb training. As presented in detail in [21], the results show great potential, with the system having a 95 % accuracy of evaluating the tutorial movements and 100 % in game evaluation. Users' feedback showed that even persons that have little to no experience in virtual reality can use it without difficulty and without experiencing any side effects if the training sessions are divided into short trials (approx. 1 hour followed by a short pause). Their suggestions also lead to improving the avatar used for reproducing the person's exercises execution in real time and in first person, as well as ameliorating the realism and the graphics of the training environments.

5. CONCLUSIONS

Telerehabilitation is an underdeveloped medical field, which could bring great benefits to patients needing physical or psychological rehabilitation. The low number of specialists compared to the number of sufferers and the lack of accessibility and flexibility of classical rehabilitation techniques are problems which can find their solutions in home-based rehabilitation systems.

Our proposed project, INREX-VR, takes advantage of virtual reality and creates a gamified setting for helping people suffering from neurological disorders recover their lost limb functionalities. Gamified elements, including entertaining tasks, visually pleasant environments, challenges or rewards, can increase motivation and lead to sustained training during a longer period of time. By creating an easy-to-use mobile application, the training process can be permanently controlled and supervised by therapists, avoiding thus communication and scheduling difficulties. Though not a low-cost system, since the complete HTC Vive Cosmos Elite package can cost approximately 1200 euros, INREX-VR can easily be adapted to less expensive devices, which can cost less than half of the previously mentioned price (one such example being Oculus Quest). This is a significant improvement when compared to robotic neurorehabilitation devices which can cost hundreds of thousands of dollars [23], therefore we consider that INREX-VR can represent a significant step forward in the field of telerehabilitation.

Received on September 1, 2021

REFERENCES

1. K. D. Boudoulas, F. Triposkiadis, C. Stefanadis, H. Boudoulas, *The endlessness evolution of medicine, continuous increase in life expectancy and constant role of the physician*, Hell. J. Cardiol., **58**, *5*, pp. 322–330 (2017).
2. L. Breniuc, C. Gyozo Haba, V. David, *Embedded platform for developing medical applications*, Rev. Roum. Sci. Techn.-Électrotechn. Énerg., **65**, *1–2* (2020).
3. N. Bentabet, N. Berrached, *An efficient asynchronous brain-computer interface for assistive technology: A novel approach*, Rev. Roum. Sci. Techn.-Électrotechn. Énerg., **65**, *1–2* (2020).
4. I.-C. Stanica, F. Moldoveanu, M.-I. Dascalu, A. Moldoveanu, G.-P. Portelli, C. N. Bodea, *Neurorehabilitation system using virtual reality and myo armband for patients and medical personnel training*, Rev. Roum. Sci. Techn.-Électrotechn. Énerg., **65**, *1–2* (2020).
5. R.-M. Baerov, A.-M. Morega, M. Morega, *Analysis of magnetotherapy effects for post-traumatic recovery of limb fractures*, Rev. Roum. Sci. Techn.-Électrotechn. Énerg., **65**, *1–2*, pp. 145–150 (2020).
6. V. Feigin, E. Nichols, T. Alam, *Global, regional, and national burden of neurological disorders, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016*, Lancet Neurol., **18**, *5*, pp. 459–480 (2019).
7. World Health Organization, *The need to scale up rehabilitation - Global need for rehabilitation* (2017).
8. E. M. Strehle, N. Shabde, *One hundred years of telemedicine: does this new technology have a place in paediatrics?*, Arch. Dis. Child., **91**, *12*, pp. 956–959 (2006).
9. World Health Organization, *Telemedicine: opportunities and developments in Member States: report on the second global survey on eHealth.*, WHO Glob. Obs. eHealth. (2010).
10. S. Wallask, T. Hollman, *What is telemedicine (telehealth)? - Definition from WhatIs.com*. https://searchhealthit.techtarget.com/definition/telemedicine
11. J. Craig, V. Patterson, *Introduction to the practice of telemedicine*, J. Telemed. Telecare, **11**, *1*, pp. 3–9 (2005).
12. H. Shirzadfar, *The evolution and transformation of telemedicine*, Int. J. Biosens. Bioelectron., **3**, *4* (2017).
13. A. Allen, D. Allend, *Telemental Health Services Today*, Telemed. Today, **2**, *1*, pp. 12–24 (1994).
14. K. Martinez, *Telemedicine benefits, disadvantages, and uses*, *Medical News Today*. https://www.medicalnewstoday.com/articles/telemedicine-benefits#benefits.
15. M. Zampolini, E. Todeschini, M. B. Guitart, H. Hermens, S. Ilsbroukx, *Tele-rehabilitation: present and future.*, Ann. Ist. Super. Sanita, **44**, *2*, pp. 125–134 (2008).
16. A. Peretti, F. Amenta, S. K. Tayebati, G. Nittari, S. S. Mahdi, *Telerehabilitation: Review of the State-of-the-Art and Areas of Application*, JMIR Rehabil. Assist. Technol., **4**, *2* (2017).
17. E. Larson, M. Feigon, P. Gagliardo, A. Dvorkin, *Virtual reality and cognitive rehabilitation: a review of current outcome research*, NeuroRehabilitation, **34**, *4*, pp. 759–772 (2014).
18. Rehab@Home Project CORDIS, *Engaging Game-based Home Rehabilitation for Improved Quality of Life* https://cordis.europa.eu/project/id/306113.
19. M. Villiger, J. Liviero, L. Awai, *Home-based virtual reality-augmented training improves lower limb muscle strength, balance, and functional mobility following chronic incomplete spinal cord injury*, Front. Neurol., **8**, pp. 1–8 (2017).
20. O.-M. Ferche, A. Moldoveanu, F. Moldoveanu, M.-I. Dascălu, R.-G. Lupu, C.-N. Bodea, *Deep Understanding Of Augmented Feedback And Associated Cortical Activations, For Efficient Virtual Reality Based Neuromotor Rehabilitation*, Rev. Roum. Sci. Techn.-Électrotechn. Énerg., **63**, *2*, pp. 233–239 (2018).
21. I.-C. Stanica, F. Moldoveanu, G.-P. Portelli, M.-I. Dascalu, A. Moldoveanu, M. G. Ristea, *Flexible Virtual Reality System for Neurorehabilitation and Quality of Life Improvement*, Sensors, **20**, p. 6045 (2020).
22. Proyecto 26, *Rest Client for Unity*. Unity Asset Store, 2018. https://assetstore.unity.com/packages/tools/network/rest-client-for-unity-102501
23. G. Carpino, A. Pezzola, M. Urbano, E. Guglielmelli, *Assessing Effectiveness and Costs in Robot-Mediated Lower Limbs Rehabilitation: A Meta-Analysis and State of the Art*, J. Healthc. Eng., doi: 10.1155/2018/7492024 (2018).