Upper-Limb Physical Rehabilitation with Techology

Subjects: Automation & Control Systems | Sport Sciences

Contributor: Andrea Catherine Alarcón-Aldana , Mauro Callejas-Cuervo , Antonio Padilha Lanari Bo

The use of videogames and motion capture systems in physical rehabilitation contributes to the recovery of the patient, for this reason, there is a tendency to continue generating proposals that face the challenges of rehabilitation with technologies that offer precision and care coverage, and that, additionally, integrate elements that promote the motivation and participation of the patient.

serious videogames | motion capture | upper limbs | physical rehabilitation | telerehabilitation | inertial sensors | inertial measurement unit (IMU)

1. Introduction

One of the sustainable development objectives suggested by the United Nations (UN) is oriented toward the universal and integral coverage of health services, and the reduction of its inequalities, in order for everyone to be in good health [1]. In accordance with the above, it is taken into account that inequalities contribute to millions of people with disabilities facing difficulties in carrying out their basic daily activities. This is more pronounced among people from communities with fewer opportunities and resources, which are generally geographically located in areas that are distant from the services required for rehabilitation processes [2].

Of the different types of disabilities, motor disability is considered to be one of the main limitations to human beings carrying out their basic activities, affecting the quality of life of the individual, as well as that of those around them [3]. In the last few years, telemedicine and telerehabilitation have been strengthened with the implementation of diverse technologies that support rehabilitation processes, oriented toward providing patients with the services required, reducing the number of journeys to main cities, where, in general, specialists, hospitals, clinics, and centers equipped with the technology for the therapies are located. The benefits of telemedicine are more evident in cases associated with traveling and the mobility of the patient, costs, or other factors, for instance, in a situation of isolation or confinement such as that experienced worldwide due to COVID 19, which does not allow people to travel somewhere that is adapted for the necessary therapy session for the patients' recovery [4].

Although in the last few years there have been many technological proposals that support physical rehabilitation, there are still difficulties and gaps in the area which represent an opportunity to contribute to improvements in biomechanical data capture accuracy, the coverage and affordability of health services, and the flexibility and motivation offered to the patients.

2. Upper Limb Physical Rehabilitation Using Serious Videogames and Motion Capture Systems

According to the importance of physical and functional rehabilitation in the quality of life of patients and the people around them, in this review, the technological contributions developed in the past few years in this field were identified, mainly regarding the inclusion of videogames and motion capture systems as support in the motor recovery of the upper limb. In the literature, a wide use of Kinect was identified as the motion capture system, although there were some limits regarding the movements carried out in the depth and occlusal planes of the limbs, i.e., the visual interruption between the camera and some of the body segments, as well as the capture of data in some specific positions (for example, sitting). Furthermore, aspects related to precision were considered in [5][6][7][8], with greater emphasis when it comes to physical rehabilitation, where precision can be a determining factor in the process. Even so, this sensor was used as a complement in the motor recovery therapies or in works focused on the validation of different attributes such as the usability of the technologies proposed or the verification of motion evaluation methods [9][10][11][12][13][14][15][16]. Among commercial products, not only Microsoft Kinect was used; the use of Nintendo Wii with its Balance Board and the Myo bracelet was reported, allowing validations in the medical field thanks to the fact that they have a lesser cost in comparison with clinical systems, such as Vicon, OptiTrack, and Qualisys, among others.

In this sense, comparisons were made of different motion capture systems with respect to Vicon, OptiTrack, or Qualisys considered to be the gold standard, against which those systems using inertial measurement units have shown a comparable performance [17][18][19][20][21][8] denoting the reliability, accessibility, accuracy, and portability offered by IMUs. In this way, inertial sensors become a good option to be used in the medical field to support motor and functional recovery processes, which require precise measurements with an accessible cost in order to be mass-produced.

Currently, novel motion capture technology involving video alone is available. Using tools from machine learning, researchers have demonstrated that tracking joints of multiple human figures may be achieved [22]. The potential of this approach is enormous, since it would enable implementing games for rehabilitation using hardware available in most dwellings. Nevertheless, for real-time operation, these methods still require powerful graphics hardware, which limits their availability at the moment.

On the other hand, the use of serious videogames has increased due to the lack of motivation of patients when they are in the process of motor recovery. In the face of this, individual, cooperative, and competitive video games have been used. Commercial video games were used in [23][24][25][26][14], which, despite encouraging the execution of physical activity and supporting the player's motivation, were not adapted to the particular characteristics of physical rehabilitation. For this reason, most of the studies proposed active video games specifically for rehabilitation, to increase motivation and adherence to therapies [27][28][29][30][11][12][13][15][16][31], in some cases associated with a configuration module allowing the health professional to adjust the characteristics of the game according to the diagnosis and progress of the patient in treatment [32][9][10]. In the particular case of commercial

rehabilitation products, such as ArmeoSenso, Bimeo, or JRS Wave, they respond adequately to such requirements in the area of physical rehabilitation, although the additional costs involved must be taken into account.

When referring to the use of commercial products, i.e., videogames and motion capture systems, it should be noted that they are an important contribution to the field of rehabilitation. However, they are not certified as medical products [30] and, therefore, to include them in a clinical routine, it is recommended that a thorough preliminary study be carried out or, if possible, a design and development procedure, guided by health professionals, to obtain products that respond to the specific needs of the rehabilitation process. Among the particular characteristics of a videogame for rehabilitation, it is worth mentioning that it should have simple visual backgrounds, clinical diagrams in accordance with the patient's situation, and configurability in terms of range of movement, speed, and recovery time, among other aspects of the process [13].

Although this review included works that used videogames and motion capture systems in physical rehabilitation, not all the works analyzed integrate these components into a single product or system, i.e., the information generated by these technologies was disconnected, making complete and timely analysis difficult in motor recovery therapy.

One of the fundamental aspects in order to achieve the objectives of a physical rehabilitation process is that it is adequately monitored and controlled, and that it is adjustable in a timely manner regardless of whether the patient and the health professional are in the same geographical location or not. For this reason, an optimal system to support physical rehabilitation should integrate various functionalities and technologies, including an accurate and portable motion capture system, as well as a customized active video game module to encourage patient motivation and guide them properly in the execution of therapy. It is also important that the system has a management and monitoring module of the rehabilitation plan assigned to each patient in real time, making it possible to manage the electronic medical record of rehabilitation processes.

In this sense, out of the works included in this review only five presented home rehabilitation systems that allow the therapist to remotely adjust and monitor the configuration of the game according to the patient's rehabilitation objectives, incorporating the recording of information in an associated computer system. Out of these, in [27], IMUs are used, in [32][29][26] the Kinect sensor was used, and two of the three works analyzed in [16] used the 5DT Data Glove Ultra and the Nintendo Wiimote. Moreover, in four of these five works, videogames developed specifically for rehabilitation were proposed. In this sense, it was identified that this type of system offers a significant contribution to the processes of motor recovery and that it is important that the information gained from the therapies carried out by a patient in a location is convenient for them and registered correctly, such that the process is evaluated in a timely and reliable manner. Thus, telerehabilitation involving a system with these components offers proper support for the management of the process, benefitting patients, their caregivers, and the medical team involved.

3. Conclusions

The ability to carry out basic daily activities autonomously is an aspect related to an individual's quality of life. People can lose their mobility and their capacity to execute daily activities for different reasons, as in the case of neurologic diseases or other clinical conditions. In order to recover functionality, physical rehabilitation systems are implemented that require, in addition to knowledge and orientation from professionals in the area, tools and technologies which provide precision and optimize the process. Motivation and commitment of the patient are also required, as reported in the works analyzed in this research.

It was found that, concerning motion capture systems, the use of Microsoft Kinect is prominent, due to its affordability and ease of use. There was also a strong trend regarding the implementation of IMUs given their precision and portability.

Concerning the affordability of the technologies used, it can be stated that most of the works used commercial systems and complemented them with the development of components allowing the adjustment of the technology to rehabilitation processes. Development mainly involved personalized and configurable videogames that respond to some requirements of the motor rehabilitation process, especially attending to the need to foment, increase, and maintain the motivation of the patient in the execution of the therapy. In general, the works showed the advantages provided by the use of active videogames in the recovery of patients, as long as they are designed and developed with the accompaniment of physical and functional rehabilitation professionals, and that they can be used in the patient's environment.

The studies analyzed included videogames, as well as motion capture systems, although only 26% of these works integrated the different components into one sole product and complemented them with a system that manages the data of the patients for respective monitoring throughout therapy. Thus, in general, it identified that an optimal system to support physical rehabilitation should include a motion capture system that offers precision and portability, a module of active videogames that are configurable to the particular needs of each patient's recovery, which permit motivation and proper guidance in the execution of the therapies and, lastly, a computer system which allows the management and monitoring of the rehabilitation plan assigned to each patient, attending to the fundamental aspects of telerehabilitation.

References

1. PNUD Objetivos de Desarrollo Sostenible | PNUD. Available online: https://www.undp.org/content/undp/es/home/sustainable-development-goals.html (accessed on 8 November 2019).
2. World Health Organization; The World Bank. World Report on Disability; WHO Press: Geneva, Switzerland, 2011.
3. International Disability Alliance | International Disability Alliance. Available online: http://www.internationaldisabilityalliance.org/ (accessed on 3 February 2020).

4. Turolla, A.; Rossettini, G.; Viceconti, A.; Palese, A.; Geri, T. Musculoskeletal Physical Therapy During the COVID-19 Pandemic: Is Telerehabilitation the Answer? Phys. Ther. 2020, 100, 1260–1264.
5. Naeemabadi, M.R.; Dinesen, B.; Andersen, O.K.; Najafi, S.; Hansen, J. Evaluating accuracy and usability of microsoft kinect sensors and wearable sensor for tele knee rehabilitation after knee operation. In Proceedings of the 11th International Joint Conference on Biomedical Engineering Systems and Technologies, Madeira, Portugal, 19–21 January 2018; pp. 128–135.
6. Schlagenhauf, F.; Sreeram, S.; Singhose, W. Comparison of Kinect and Vicon Motion Capture of Upper-Body Joint Angle Tracking. In Proceedings of the 2018 IEEE 14th International Conference on Control and Automation (ICCA), Anchorage, AK, USA, 12–15 June 2018; pp. 674–679.
7. Napoli, A.; Glass, S.; Ward, C.; Tucker, C.; Obeid, I. Performance analysis of a generalized motion capture system using microsoft kinect 2.0. Biomed. Signal Process. Control 2017, 38, 265–280.
8. Callejas-cuervo, M.; Gutierrez, R.M.; Hernandez, A.I. Joint amplitude MEMS based measurement platform for low cost and high accessibility telerehabilitation: Elbow case study. J. Bodyw. Mov. Ther. 2016, 21, 574–581.
9. Fuertes, G.; Mollineda, R.; Gallardo, J.; Pla, F. A RGBD-Based Interactive System for Gaming-Driven Rehabilitation of Upper Limbs. Sensors 2019, 19, 3478.
10. Ma, M.; Proffitt, R.; Skubic, M. Validation of a Kinect V2 based rehabilitation game. PLoS ONE 2018, 13, 1–15.
11. Yang, Z.; Rafiei, M.H.; Hall, A.; Thomas, C.; Midtlien, H.A.; Hasselbach, A.; Adeli, H.; Gauthier, L.V. A Novel Methodology for Extracting and Evaluating Therapeutic Movements in Game-Based Motion Capture Rehabilitation Systems. J. Med. Syst. 2018, 42.
12. Da, J.S.; Neto, C.; Filho, P.P.R.; Ferreira, G.P.; Silva, D.A.; Da, N.B.; Olegario, C.; Duarte, B.F.; Albuquerque, V.H.C.D.E.; Ao, J.O. Dynamic Evaluation and Treatment of the Movement Amplitude Using Kinect Sensor. IEEE Access 2018, 6, 17292–17305.
13. Bonnechère, B.; Jansen, B.; Haack, I.; Omelina, L.; Feipel, V.; Jan, S.V.S.; Pandolfo, M. Automated functional upper limb evaluation of patients with Friedreich ataxia using serious games rehabilitation exercises. J. Neuroeng. Rehabil. 2018, 15, 1–9.
14. Bird, M.L.; Cannell, J.; Callisaya, M.L.; Moles, E.; Rathjen, A.; Lane, K.; Tyson, A.; Smith, S. “FIND Technology”: Investigating the feasibility, efficacy and safety of controller- free interactive digital rehabilitation technology in an inpatient stroke population: Study protocol for a randomized controlled trial. Trials 2016, 17, 1–6.
15. Mobini, A.; Behzadipour, S.; Saadat, M. Test–retest reliability of Kinect ’ s measurements for the evaluation of upper body recovery of stroke patients. Biomed. Eng. OnLine 2015, 14, 1–13.

16. Nathan, D.; Huynh, D.Q.; Rubenson, J.; Rosenberg, M. Estimating Physical Activity Energy Expenditure with the Kinect Sensor in an Exergaming Environment. PLoS ONE 2015, 10, 1–22.
17. Sers, R.; Forrester, S.; Moss, E.; Ward, S.; Ma, J.; Zecca, M. Validity of the Perception Neuron inertial motion capture system for upper body motion analysis. Meas. J. Int. Meas. Confed. 2020, 149, 107024.
18. Feuvrier, F.; Sijobert, B.; Azevedo, C.; Griffiths, K.; Alonso, S.; Dupeyron, A.; Laffont, I.; Froger, J. Inertial measurement unit compared to an optical motion capturing system in post-stroke individuals with foot-drop syndrome. Ann. Phys. Rehabil. Med. 2019, 63, 195–201.
19. Khobkhun, F.; Hollands, M.A.; Richards, J.; Ajjimaporn, A. Can we accurately measure axial segment coordination during turning using inertial measurement units (IMUs)? Sensors 2020, 20, 2518.
20. Beange, K.H.E.; Chan, A.D.C.; Beaudette, S.M.; Graham, R.B. Concurrent validity of a wearable IMU for objective assessments of functional movement quality and control of the lumbar spine. J. Biomech. 2019, 97, 109356.
21. Hafer, J.F.; Provenzano, S.G.; Kern, K.L.; Agresta, C.E.; Grant, J.A.; Zernicke, R.F. Measuring markers of aging and knee osteoarthritis gait using inertial measurement units. J. Biomech. 2020, 99, 109567.
22. Cao, Z.; Hidalgo Martinez, G.; Simon, T.; Wei, S.-E.; Sheikh, Y.A. OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields. IEEE Trans. Pattern Anal. Mach. Intell. 2019, 1–14.
23. MacIntosh, A.; Desailly, E.; Vignais, N.; Vigneron, V.; Biddiss, E. A biofeedback-enhanced therapeutic exercise video game intervention for young people with cerebral palsy: A randomized single-case experimental design feasibility study. PLoS ONE 2020, 15, e0234767.
24. Wittmann, F.; Lambercy, O.; Gassert, R. Magnetometer-Based Drift Correction During Rest in IMU Arm Motion Tracking. Sensors 2019, 19, 1312.
25. Goršič, M.; Cikajlo, I.; Novak, D. Competitive and cooperative arm rehabilitation games played by a patient and unimpaired person: Effects on motivation and exercise intensity. J. Neuroeng. Rehabil. 2017, 14, 1–18.
26. Wittmann, F.; Held, J.P.; Lambercy, O.; Starkey, M.L.; Curt, A.; Höver, R.; Gassert, R.; Luft, A.R.; Gonzenbach, R.R. Self-directed arm therapy at home after stroke with a sensor-based virtual reality training system. J. Neuroeng. Rehabil. 2016, 13, 1–10.
27. Condino, S.; Turini, G.; Viglialoro, R.; Gesi, M.; Ferrari, V. Wearable Augmented Reality Application for Shoulder Rehabilitation. Electronics 2019, 8, 1178.

28. Lui, J.; Menon, C. Would a thermal sensor improve arm motion classification accuracy of a single wrist—Mounted inertial device? Biomed. Eng. Online 2019, 18, 1–17.
29. Fernandes, F.G.; Cardoso, A.; Lopes, R.D.A. Games applied to children with motor impairment using the myo wearable device. An. Acad. Bras. Cienc. 2020, 92, 1–14.
30. David, V.; Forjan, M.; Paštěka, R.; Scherer, M.; Hofstätter, O. Development of a multi-purpose easy-to-use set of tools for home based rehabilitation: Use cases and applications developed during the rehabitation project. ACM Int. Conf. Proc. Ser. 2018, 323–330.
31. Basteris, A.; Nijenhuis, S.M.; Buurke, J.H.; Prange, G.B. Lag—Lead based assessment and adaptation of exercise speed for stroke survivors. Rob. Auton. Syst. 2015, 73, 144–154.
32. Agyeman, M.O.; Al-Mahmood, A.; Hoxha, I. A Home Rehabilitation System Motivating Stroke Patients with Upper and/or Lower Limb Disability. ACM Int. Conf. Proceeding Ser. 2019.