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IMPLEMENTATION OF ROBOTIC AND ASSISTIVE TECHNOLOGIES IN THE PATIENT-CENTERED PHYSICAL REHABILITATION

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ABSTRACT

There is a necessity for a consistent framework for the integration of the robotic and assistive technologies for the purposes of the rehabilitation which covers the entire spectrum (preventative, restorative, supportive, palliative rehabilitation) and explores all aspects of the of the recovery process – physical, emotional, and mental while allowing for real-time adjustments and flexibility based on the individual patients' needs. In this paper we propose a set of tools for a rehabilitation solution that provides personalized care for the patients from the diagnose to the process of active recovery while measuring and evaluating the individual's condition after surgery, injury or a trauma to restore and maximize the previous function. The main objective for implementing the assistive technologies into the physical therapy is to personalize the process of recovery based on the specific requirements of the patients. To achieve this, physical, emotional, and virtual devices are utilized mitigate and improve the physical and emotional challenges for the patients. In parallel with the implementation of the robotic technologies, custom-made 3D printed devices are also introduced and explored. To evaluate the effectiveness of the program, a 3-step methodology is applied – 1) diagnose of the patient, 2) implementation of the assistive technologies, 3) tracking the progress and making the necessary adjustments to the process and/or the devices.

1. INTRODUCTION

The main focus of this study is to develop a new rehabilitation framework integrating the physical, virtual, and emotional robotic and assistive technologies for the needs of the physical rehabilitation which will lead to outcomes set and driven by the patient's condition and progress.

According to a recent report, 2.41 billion or 1 in 3 individuals worldwide live with the conditions that impact their functions in daily life and would benefit from rehabilitation therapy [1], [2]. Within the next 30 years the population over 60 years will double, the majority of whom will live with chronic diseases. This demographic distribution change will lead to a great amount of unmet rehabilitation needs [2].

Rehabilitation focuses on reaching functional independence in daily activities, work, recreation and education, while taking a meaningful role throughout those activities. Rehabilitation is a set of interventions designed to optimise functioning in individuals with health conditions (diseases – acute or chronic, injuries or trauma, aging, stress or genetic predisposition) in interaction with their environment. It consists of 4 parts [3]: preventative, restorative, supportive and palliative rehabilitation. *Preventative*: takes place shortly after a new diagnosis or onset of new impairments. The aim is to provide education, advice and interventions to prevent or slow down the onset of further impairments and maintain a person's level of ability. *Restorative*: focuses on interventions that improve impairments such as muscle strength or respiratory function and, in cognitive impairment, to get maximal recovery of function. *Supportive*: Supportive rehabilitation increases a person's self-care ability and mobility using methods such as providing self-help devices and teaching people compensatory strategies or alternative ways of doing things. *Palliative*: enables people with life limiting conditions to lead a high quality of life physically, psychologically and socially, while respecting their wishes. It often focusses on relieving symptoms such as pain, dyspnoea and oedema, preventing contractures, breathing assistance, psychological wellbeing, relaxation, or the use of assistive device in order to maximise the functional independence and support comfort, dignity and quality of life. This work aims at including all 4 parts of the rehabilitation within the same framework.

Amongst the reasons for using robots in the rehabilitation process is to provide therapy which is superior to conventional therapy [4], [5], [6], [7]. In addition to the incorporated robotic technologies, custom designed and fabricated devices, tuned to the patients' specific requirements, are also explored, evaluated and implemented to address the aspects of customization and especially in the low-budget solutions where currently there is a lack of wearable options due to the cost limitations.

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To enhance the emotional state of the patients, a set of scenarios and games will be developed and integrated in parallel with the physical solutions to assess and help measure the emotional and neurological progress of the therapy and make the process more engaging via adopting virtual and mixed reality headsets. These devices allow for real-time feedback and therefore, evaluation of the performance by a visual or haptic input, which makes them suitable for motion restoration activities [8].

Another component of the framework is the Socially assistive robots (SARs) which help patients to process negative emotions and develop healthy and engaging strategies, reducing stress and improving the overall emotional well-being by adjusting to the physical and social changes related to their condition and recovery [9]. SARs can also help patients to improve their social skills, increase their confidence and overall experience during rehabilitation. Combining physical and emotional rehabilitation will lead to faster recovery of the injured patient. The humanoid socially assistive robots of type Pepper and Nao will participate as mediators in the rehabilitation sessions 24/7 in the Intensive Care Units (ICU) or other Burn and Injury Departments (BID) as in [10], [11]. The robots will be programed to start the rehabilitation process as soon as possible after the intervention by either emotionally engaging the patients or showing the movements required for the rehabilitation process (via the embedded "Motion animation mode" to mimic human movements) for the purposes of the emotional rehabilitation or partial assistance of the physical rehabilitation, respectively. These robot animations will be used in the ICU or other departments and show the movements in the rehabilitation protocol, in case of the Range of Motion (ROM) of the robot is suitable for that purpose.

2. DISCUSSION AND RESULTS

The current state of the art accounts for either only the *physical*, or the *emotional*, aspect of the rehabilitation process. Furthermore, the application of robotic devices is not widespread, these are not accessible without the guidance of experts, and do not fully cover the condition of the patients. The proposed integrated framework for physical, virtual, and emotional robotic devices in sensorimotor rehabilitation therapy is illustrated at Figure 1. This integration leads to interconnection between physical and emotional states, where improving one component helps the other and vice versa.

Such implementation will lead to the following benefits:

- fast response to the patients' needs;
- flexibility for providing individual and customized treatment based on the diagnosis;
- adjustment of the level of difficulty of the exercises according to the patient's condition;
- the robot can execute repetitive tasks tirelessly.

These assistive technologies are applicable in have different stages of the rehabilitation process as shown in Table 1.

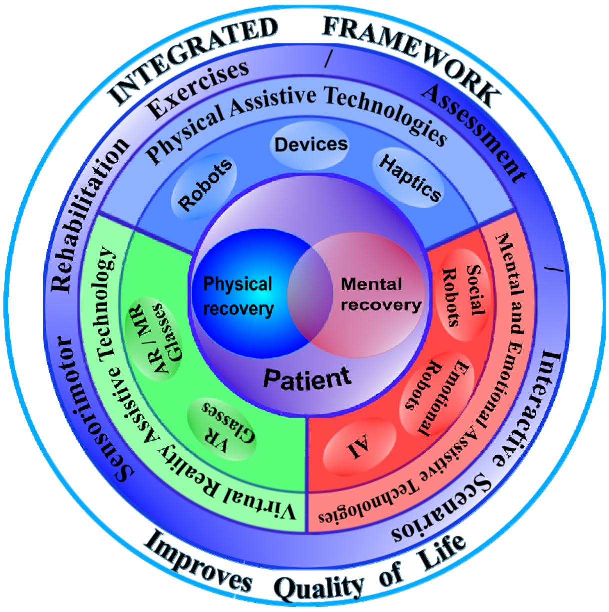


Fig. 1. Integrated Framework for Person-centered Rehabilitation

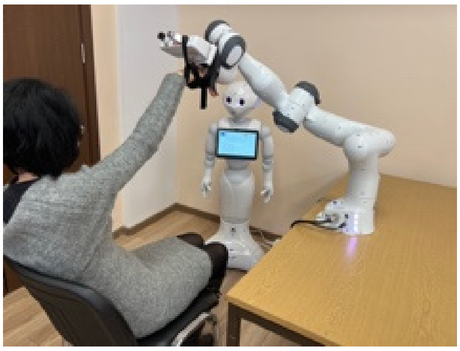
Table 1 *Implementation of the Technical Solutions for the Various Stages of the Rehabilitation*

Technology	Investigate	Evaluate	Improve
Collaborative Robot	✗	✓	✓
3D Printing & 3D Scanning	✗	✗	✓
Haptic Devices	✗	✓	✓
AR/VR	✗	✓	✓
Motion Capture System	✓	✗	✗
BCI	✓	✗	✗
Smart Wearables	✓	✓	✓
Socially-assistive Robots	✗	✓	✓

Figure 2 shows example applications of the assistive technologies in the physical rehabilitation.

In Figure 2 a), an application of a collaborative robot for the needs of the upper limb range of motion and strength recovery is illustrated; b) shows the restoration of the fine motor skills of wrist with the help of a haptic devise that provides resistance during motion; c) presents an implementation of a 3D scanner for precisely measuring the shape and form of the patient's hand to create ergonomic, light weighted and personalized assistive devices; d) is a 3D Printed knee supportive device with customized parameters. Some of the factors that must be considered in the designing phase of such devices is their range of motion and stiffness based on the state of the patient's recovery. This influence is addressed on Figure 3 where a set of interchangeable assistive devices for ACL (Anterior Cruciate Ligament) rehabilitation with different stiffness to range ratios are provided.

As it can be clearly observed, the distribution of the moments and compatibility of the supports. By varying the parameters such as the radius of the curvature and the number of flexures, more individual solutions could be generated.



a)

b)

c)

d)

Fig. 2. Example Applications of the Assistive Technologies in the Physical Rehabilitation

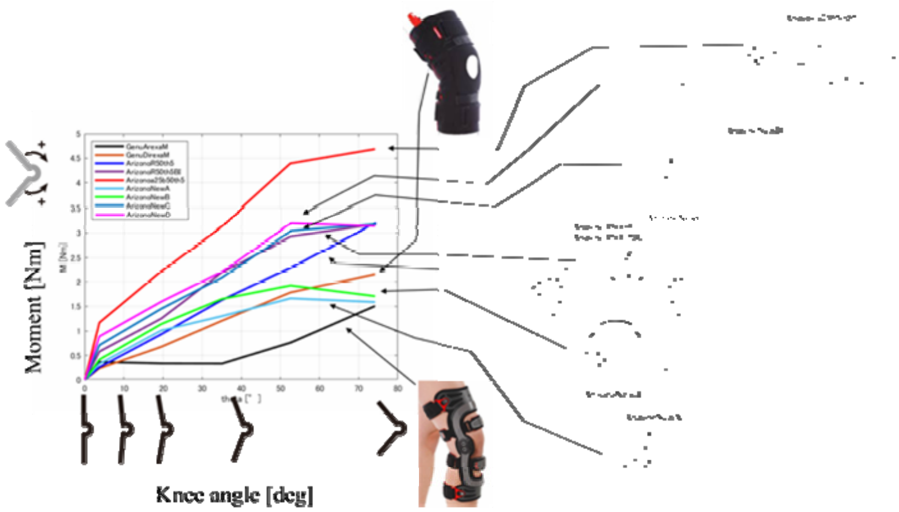


Fig. 3. Grading the 3D Printed Supports Based on their Peak Moments

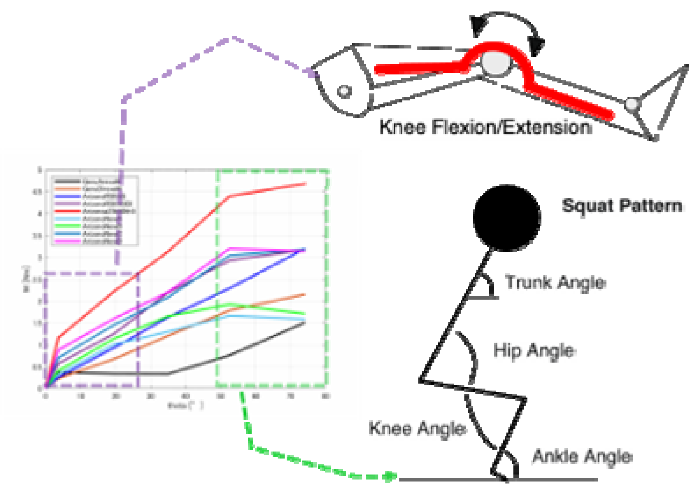


Fig. 4. Implementation of the Assistive Devices into the Rehabilitation Process

In addition, the exercise recommendation is prescribed based on the recovery status as illustrated on Figure 4. For initial peak moments shown on Figure 4 the supports are used for improving the resisted knee flexion through concentric contractions and resisted knee extension eccentrically. After the ROM and the quadriceps strength improve, the patient can transition to a device with a greater stiffness in order to further increase the muscular strength during knee flexion and extension. When the patient can perform full ROM controlled knee flexion with the stiffest support, they can transition to another exercise such as the squat pattern. For the squat, the patient starts with the stiffest support that will provide the highest level of stability and gradually transitions towards the more flexible options until they no longer need any additional assistance and are capable of performing the motion on their own.

The methodology of this study integrates different stages of the rehabilitation process and aims to provide a complete recovery of the patients, including physical, emotional, and mental support. To achieve this goal, the implementation of the assistive robotic technologies depends on the stage of recovery. To make the process as objective as possible, the methodology, adopted in this study, is divided into 3 levels. First, is to investigate the condition and the diagnosis of the patient. At this stage, based on the condition, initial parameters will be established, measured, and tracked. Next, the process of evaluation will define the complexity of the condition and the required technologies to be implemented in order to accelerate the healing of the patient. Finally, the last step is the implementation of the technologies into the rehabilitation protocols, tracking of the improvement and adjustment of the process, based on the specific personal necessities and requirements.

Rehabilitation, as a highly person-centered process, needs to be tailored toward individual specifics of each patient which requires real-time adjustments. Implementing the robotic technologies will give that flexibility to the therapists and extend their field of operation. To target all stages of the rehabilitation, various types of assistive technologies and devices will be implemented – robots, custom-made assistive systems, virtual and mixed reality headsets, integrated with interactive scenarios, tools for monitoring the telerehabilitation, enhancement of the emotional and mental recovery as well as artificial intelligence algorithms to allow personalized data analysis and real-time adjustments of the solutions by improving the trained models. This methodology will carry the following benefits:

- unified rehabilitation protocol;
- implementation of the optimal technology;
- quick reaction to the patient’s condition;
- flexible customized solutions, depending on the individual requirements;
- real-time adjustments to the process regarding the current condition of the patients.

To incorporate the above methodology into modern rehabilitation, there are several challenges that need to be addressed and overcome. Defining the parameters to track and measure with the robotic equipment is such a complex matter. To resolve this, the experts in charge with the technical solutions will be working closely with the medical professionals throughout all steps to determine the most relevant data-driven processes. Another one is the integration of the interactive scenarios to work coherently with the virtual reality glasses. To accomplish such an integration, the software developers will need to follow the medical requirements provided by the physicians as an input for their platforms.

3. CONCLUSION

This research introduces a novel framework for implementation of robotic and assistive technologies in the process of physical rehabilitation while acknowledging the influence of the emotional and mental state of the patients on their physical condition and vice versa. In other words, all aspects and stages of the rehabilitation, their connections and relations are explored. Furthermore, the real-time progress tracking and adjustment requirements are discussed to improve the process and provide customized solution for the patients. The framework includes the implementation of physical devices such as robots, virtual reality headsets for emotional release as well as custom-made patient specific supports after injuries, stroke recovery and trauma. The integration of 3D printing and 3D scanning is explained and illustrated. Lastly, a methodology for evaluation of the patients’ condition, technology selection, progress tracking is introduced and integrated.

This study recognizes the limitations caused by the budget restrictions and expertise requirements for the full implementation of the novel framework in the rehabilitation protocols. However, the availability and accessibility of the robotics in parallel with the modern days rapid technological advancements will inevitably lead to mitigating the impact of these challenges and soon lifting all barriers holding the progress and innovations in the field of rehabilitation.

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REFERENCES

[1] Duttine A., Battello J., Beaujolais A., Hailemariam M., Mac-Seing M., Mukangwije P. et al. Introduction to Rehabilitation Factsheet, Handicap International (2016) https://humanity-inclusion.org.uk/sn_uploads/document/2017-02-factsheet-rehabilitation-introduction-web_1.pdf, Accessed on 16.01.2023

[2] Shimizu Y., Rehabilitation. World Health Organization. (2020) https://www.who.int/news-room/fact-sheets/detail/rehabilitation, [Accessed on 16.01.2023]

[3] Introduction to Rehabilitation: https://www.physio-pedia.com/Introduction_to_Rehabilitation#cite_note-:1-2, [Accessed on 16.01.2023]

[4] https://www.lifescience-robotics.com/ [Accessed on 4.03.2023]

[5] https://www.youtube.com/watch?v=qotp80vfteM&t=221s [Accessed on 4.03.2023]

[6] Poli P., Morone G., Rosati G. et al., Robotic technologies and rehabilitation: new tools for stroke patients' therapy. Biomed Res Int. 2013;153872. DOI:10.1155/2013/153872

[7] Mohebbi A. Human-Robot Interaction in Rehabilitation and Assistance: a Review. Curr Robot Rep 1, 131–144 (2020) https://doi.org/10.1007/s43154-020-00015-4

[8] Quaine F., Dogadov A., Servière C., & Lopez N. Surface Electromyographic Signals as a Tool for Biomechanics and

Muscle Coordination Analysis (Doctoral dissertation, GIPSA Lab) (2022) https://hal.science/hal-03980009/document [Accessed on 28.02.2023]

[9] Tanev T., Lekova A. Implementation of Actors' Emotional Talent into Social Robots through Capture of Human Head's Motion and Basic Expression, International Journal of Social Robotics 14 (7) (2022) 1749-1766, https://doi.org/10.1007/s12369-022-00910-0

[10] Ozturkcan S., Merdin-Uygur E. (2022), Humanoid service robots: The future of healthcare? Journal of Information Technology Teaching Cases, 12 (2) (2022) 163–169, https://doi.org/10.1177/20438869211003905

[11] Dimitrova M., Essential 'Human' Features of the Cyber-Physical Nurse. Biomed J Sci & Tech Res 46(1) (2022) DOI: 10.26717/BJSTR.2022.46.007285