Traumatology and Orthopaedics of Kazakhstan
ISSN - e2789-9640

Methodological article

Integration of Virtual Reality-Based 3D Gaming With a Robotic Exoskeleton for Cognitive-Motor Rehabilitation: 3D VR System Architecture and Implementation

Sultan Omirbayev [1], Amina Abdikalyk [2], Shyngys Dauletbayev [3*], Meiram Shakenov [4], Azhar Giniayt [5]

Received: 08 January 2026
Revised: 17 February 2026
Accepted: 24 February 2026
Published: 28 February 2026

Citation: Sultan Omirbayev, Amina Abdikalyk, Shyngys Dauletbayev, Meiram Shakenov, Azhar Giniayt. Integration of Virtual Reality-Based 3D Gaming With a Robotic Exoskeleton for Cognitive-Motor Rehabilitation: 3D VR System Architecture and Implementation. Trauma & Ortho Kaz, 2026, 77 (1), jto036. https://doi.org/10.52889/1684-9280-2026-77-1-jto036

This work is licensed under a Creative Commons Attribution 4.0 International License

[1] Research Assistant, Nazarbayev University, Astana, Kazakhstan. E-mail: sultan.omirbayev@nu.edu.kz
[2] Research Assistant, Nazarbayev University, Astana, Kazakhstan. E-mail: amina.abdikalyk@nu.edu.kz
[3] Research Assistant, Nazarbayev University, Astana, Kazakhstan. E-mail: shyngys.dauletbayev@alumni.nu.edu.kz
[4] Head of Department, Strategic Development and Marketing, National Center for Children's Rehabilitation, Astana, Kazakhstan. E-mail: me.shakenov@nccr.kz
[5] Chairman of the Board, National Center for Children's Rehabilitation, Astana, Kazakhstan. E-mail: a.giniyat@nccr.kz
***Corresponding author**: shyngys.dauletbayev@alumni.nu.edu.kz

Abstract

The aim: To develop technically validate an immersive virtual reality-based rehabilitation platform integrating three-dimensional interactive environments with a robotic lower-limb exoskeleton and treadmill system for pediatric cognitive-motor rehabilitation in orthopaedic practice.
Methods. A modular immersive rehabilitation platform based on a head-mounted display system was developed to support synchronized interaction between assisted locomotion and structured cognitive tasks. The system architecture included culturally adapted interactive therapeutic environments, standardized interaction mechanics, and real-time synchronization with treadmill-assisted walking. A bidirectional communication interface was implemented to enable coordinated integration between the robotic lower-limb exoskeleton and the virtual environment. Rehabilitation sessions were structured as dual-task paradigms combining continuous assisted gait training with simultaneous cognitive decision-making activities. The platform incorporated adaptive exoskeleton assistance modes, integrated safety monitoring, and real-time recording of locomotor parameters, interaction events, task accuracy, navigation errors, and completion metrics. All collected data were stored in standardized datasets suitable for statistical analysis and future clinical investigations.
Results. Five interactive rehabilitation environments containing more than fifty task-oriented interactive elements were successfully implemented. The system demonstrated stable real-time synchronization between treadmill speed and virtual locomotion across a walking velocity range from zero point one to two meters per second. Context-dependent exoskeleton assistance modes operated consistently without communication delay or mechanical instability. Continuous safety monitoring ensured controlled interaction during training sessions. The platform generated structured datasets including gait parameters, task accuracy, navigation errors, response indicators, and completion time metrics, providing measurable outcomes for clinical research applications.
Conclusion. The developed immersive virtual rehabilitation platform provides a structured and scalable framework for pediatric cognitive-motor rehabilitation in

traumatology and orthopaedics. Its modular architecture enables safe integration with robotic exoskeleton systems, individualized task adaptation, and standardized clinical data acquisition. The system demonstrates technical readiness for pilot investigations and subsequent randomized controlled clinical trials.

Keywords: virtual reality, rehabilitation, exoskeleton devices, gait, motor skills.

1. Introduction

Virtual reality-based interventions have emerged as a promising therapeutic approach in gait rehabilitation, particularly for patients with neurological and orthopedic conditions. Immersive virtual environments allow repetitive task-oriented training while maintaining patient motivation and engagement, which are essential factors for successful rehabilitation outcomes [1-3]. In pediatric rehabilitation, maintaining attention and participation during therapy sessions can be challenging, and interactive virtual environments may provide an effective method to increase therapy intensity and adherence.

Recent studies have demonstrated that combining virtual reality with treadmill-based gait training can improve walking speed, balance, and functional mobility in patients with neurological disorders such as stroke, cerebral palsy, and multiple sclerosis [4-7]. Virtual reality exergames allow the integration of motor exercises with cognitive tasks, creating a dual-task rehabilitation paradigm that simultaneously targets motor coordination and executive function [8,9]. This approach is particularly relevant in pediatric neurorehabilitation, where cognitive-motor interaction plays an important role in functional recovery.

Robotic rehabilitation technologies, including lower-limb exoskeletons, have been increasingly introduced to provide controlled and repetitive movement assistance during gait training. These systems enable precise regulation of movement parameters and objective monitoring of patient performance [10,11]. When integrated with immersive virtual environments, robotic systems can enhance sensorimotor feedback and provide task-specific rehabilitation scenarios that mimic real-life activities.

Despite these advantages, several challenges remain in designing virtual rehabilitation systems suitable for clinical practice. Maintaining ecological validity of the virtual environment and ensuring stable synchronization between robotic devices and immersive environments are essential for safe and effective therapy. In addition, standardized data collection frameworks are necessary to enable objective evaluation of rehabilitation outcomes in clinical trials. Therefore, the aim of the present study was to develop and technically validate a virtual reality-based rehabilitation platform integrating three-dimensional gaming environments with a robotic lower-limb exoskeleton and treadmill system for cognitive–motor rehabilitation.

2. Materials and methods

Study Design

This study was conducted as a pilot experimental and technical feasibility investigation focused on the development and validation of a virtual reality–based rehabilitation platform integrated with a robotic lower-limb exoskeleton and treadmill system. No patient recruitment was performed and no clinical interventions were administered. All testing was conducted in a controlled laboratory environment to evaluate system stability, integration consistency, and readiness for future clinical studies.

System Architecture

The rehabilitation platform consisted of three integrated components: a robotic lower-limb exoskeleton providing assisted gait support, a treadmill-based locomotion system, and an immersive three-dimensional virtual reality environment. These components were connected through a control and communication layer enabling real-time bidirectional data exchange.

The virtual environment was developed using Unity 2022 Long-Term Support with the Universal Render Pipeline for optimized performance. The architecture included five functional layers: input, locomotion, interaction, integration, and data logging. The input layer processed controller signals, treadmill parameters, and exoskeleton data. The locomotion layer synchronized avatar movement with treadmill speed and assisted modes. The interaction layer standardized object selection and task mechanics across all environments. The integration layer enabled communication between hardware and software components. The data logging layer implemented event-based recording and structured export.

https://doi.org/10.52889/1684-9280-2026-77-1-jto036

Five culturally adapted environments were developed: a Kazakh village, school classroom, park, home interior, and playground (Figures 1,2). Each environment supported navigation tasks, object selection, and rule-based cognitive exercises (Table 1). Adjustable parameters included movement speed, visual density, object count, trigger radius, and cognitive rule complexity.

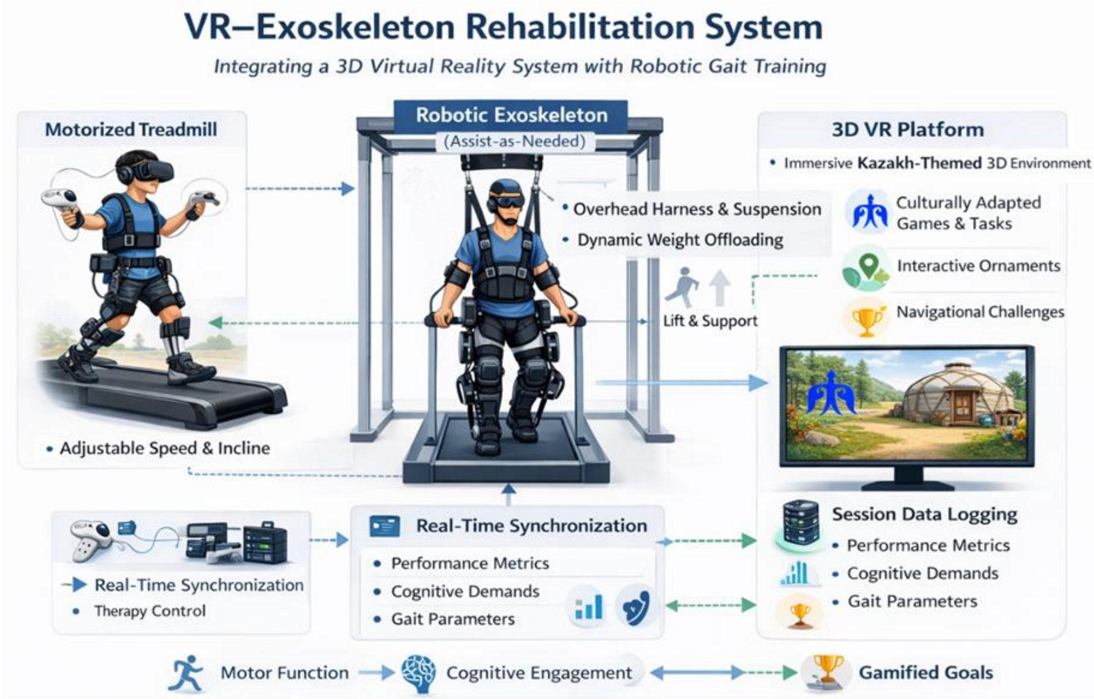

Figure 1 - Overall architecture of the VR–exoskeleton rehabilitation platform. The system integrates a robotic lower-limb exoskeleton with treadmill-based gait training and an immersive three-dimensional virtual reality environment

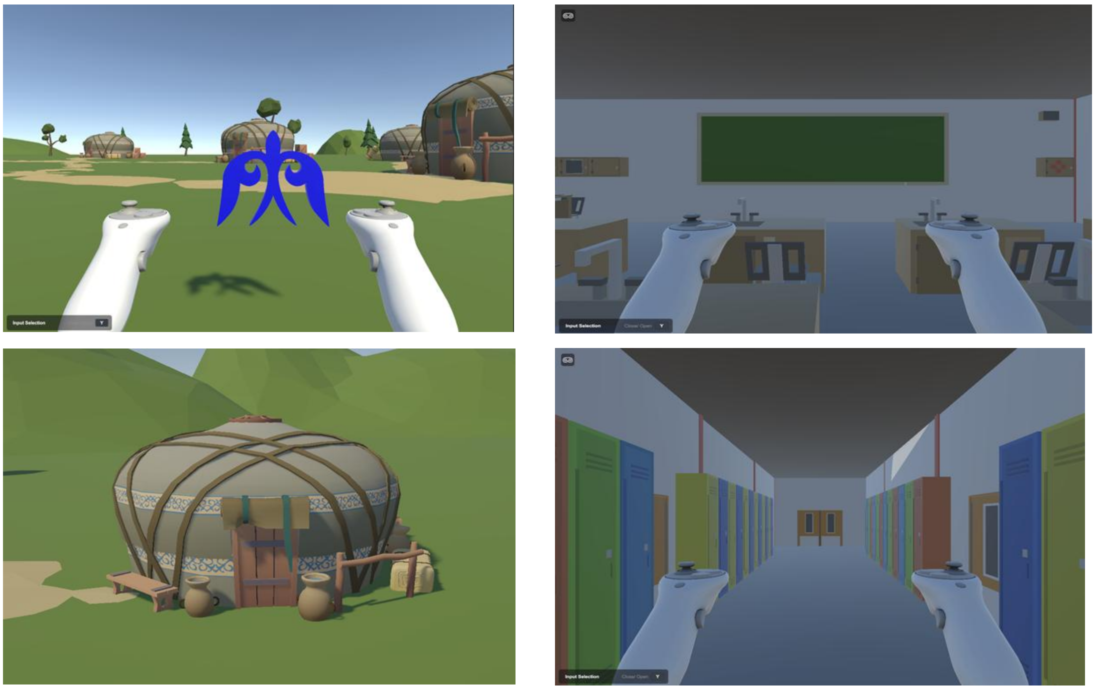

Figure 2 - 3D VR interactive environments examples

Table 1 – Culturally Adapted Assets (Kazakh Context): Composition, Purpose, and Application

Object / Asset	Category	Therapeutic Purpose	Where Used	Key Parameters
Yurt prefab	Cultural landmark	Orientation; attention maintenance	Aul scene; start/finish; checkpoints	Number of yurts; distance; trigger zones
Yurt	Interactive zone	Session start/end; stage confirmation	Aul; Park	Zone radius; confirmation required
Ornaments 5 types	Target stimuli	Selection/search/sorting; cognitive load	Aul; Classroom; Home	Type; size; contrast; density
Navigation arrows	Prompts / triggers	Decision-making; route learning	Aul; Corridor/ School	Prompt frequency; visibility; penalties
Route checkpoints	Navigation triggers	Assessment of gait stability and attention	Aul; Park	Number of points; distance; timeout
School context	Indoor context	Route planning; sequential tasks	Classroom; Corridor	Route complexity; number of turns
Park elements	Outdoor context	Mild sensory load; longer sessions	Park	Reduced object density
Home elements (room)	Indoor context	Flat object selection; low cognitive load	"Home/Room"	Limited number of prompts
Playground objects	Motivational stimuli	Reaching/selection; behavioral reinforcement	"Playground"	Number of targets; speed; task order
Unified colliders / anchor points	Technical asset	Reusable elements; XR stability	All scenes	Collider type; layer; size

Figure 3 - Experimental setup for treadmill-based robotic rehabilitation with virtual reality integration. A participant is positioned on a treadmill while secured with a body-weight support system and assisted by a lower-limb robotic exoskeleton

https://doi.org/10.52889/1684-9280-2026-77-1-jto036

Treadmill and Exoskeleton Integration

The treadmill was integrated through a modular interface providing real-time speed and incline data. Locomotion speed in the virtual environment was synchronized within a range of 0.1 to 2.0 meters per second. Emergency stop functionality was implemented with a response threshold below one hundred milliseconds.

The robotic exoskeleton was integrated through a dedicated communication interface enabling real-time bidirectional data transfer (Fig 3). Incoming data included joint angles, movement velocity, torque parameters, operational states, and safety events. Outgoing signals allowed contextual modulation of assistive parameters. Assist-as-needed strategies and predefined safety constraints were implemented to allow adjustable mechanical support.

Data Collection

An event-based logging framework recorded reaction time, task accuracy, navigation errors, rule violations, task duration, session start and stop events, and safety-related events. Data were exported in structured formats for future quantitative analysis. As this study focused on technical feasibility, no inferential statistical analysis was performed.

Statistical Considerations

As this study represented a technical feasibility and system validation investigation, no inferential statistical analysis was performed. Data logging and metric recording were implemented to support future quantitative evaluation in subsequent clinical trials.

Ethical Considerations

This study did not involve human participants, patient data, or biological materials. All testing procedures were conducted in a controlled laboratory environment. The study was designed in accordance with fundamental ethical principles for biomedical research and does not require institutional ethical approval at this stage.

3. Results

Functional validation demonstrated stable operation across all developed virtual environments. Scene loading, rendering performance, and interaction mechanics operated without interruption during structured testing sessions.

The platform successfully generated structured datasets capturing motor and cognitive performance indicators. All predefined interaction events, including object collection, checkpoint activation, rule-based triggers, and session transitions, were correctly logged. Data export was completed without system interruption.

Bidirectional communication between the virtual reality platform, treadmill, and robotic exoskeleton operated consistently. Seamless switching between simulated and real treadmill input was achieved without modification of locomotion logic. Locomotion speed remained synchronized with treadmill speed within the tested range. Emergency stop functionality operated within the defined response threshold.

Incoming exoskeleton data streams and outgoing modulation commands were transmitted and recorded successfully. Assistive parameters were adjustable during task execution without system instability. All environments maintained stable performance under varying task complexity and visual density conditions.

4. Discussion

The present study describes the development and technical validation of a virtual reality-based rehabilitation platform integrating immersive three-dimensional environments with treadmill-assisted locomotion and robotic exoskeleton support. The results demonstrate stable system integration, reliable bidirectional communication between hardware and software components, and the ability to generate structured datasets suitable for future clinical evaluation.

Virtual reality has increasingly been investigated as a rehabilitation tool due to its ability to provide interactive and motivating therapy environments. Previous studies have reported improvements in gait performance, balance control, and patient motivation when virtual reality is combined with conventional rehabilitation methods [3,5,12]. The present platform builds upon these findings by integrating immersive virtual environments with robotic-assisted gait training, which may further enhance sensorimotor stimulation during rehabilitation exercises.

The integration of robotic exoskeleton support with virtual environments enables controlled task-oriented training. Robotic systems provide consistent assistance during gait cycles while simultaneously recording biomechanical parameters that can be used for clinical assessment [10,13]. Such systems may be particularly valuable in pediatric rehabilitation, where therapy must be both engaging and adaptable to individual functional abilities.

https://doi.org/10.52889/1684-9280-2026-77-1-jto036

An important feature of the proposed platform is the incorporation of culturally adapted virtual environments. The use of locally recognizable elements within rehabilitation scenarios may improve patient engagement and ecological validity of the training environment. Previous studies suggest that immersive and contextually meaningful environments can enhance motivation and adherence to therapy programs [8,9].

Another advantage of the proposed system is its modular architecture and standardized data logging framework. Structured data collection enables objective evaluation of patient performance and supports the design of randomized controlled trials investigating the clinical effectiveness of immersive rehabilitation technologies.

However, several limitations should be acknowledged. The present investigation focused on technical feasibility and system validation and did not include clinical participants. Consequently, the therapeutic effectiveness of the platform remains to be evaluated in real patient populations. Future studies should investigate safety, usability, and clinical outcomes in children undergoing rehabilitation for neurological or orthopaedic conditions [14–16].

5. Conclusions

A virtual reality-based rehabilitation system integrating three-dimensional gaming environments, treadmill-based locomotion, and robotic exoskeleton support was developed and technically validated. The system architecture enables structured cognitive–motor dual-task training, real-time bidirectional device communication, and standardized performance data collection suitable for future clinical investigation. Functional testing demonstrated stable operation across multiple immersive environments and reliable synchronization between hardware and software components. While therapeutic effectiveness has not yet been evaluated in patient populations, the implemented framework provides a scalable and reproducible foundation for subsequent clinical validation studies in pediatric neurorehabilitation.

Conflict of interests. The authors declare no conflict of interest.

Acknowledgements. The authors thank the Ministry of Science and Higher Education of the Republic of Kazakhstan for supporting this study.

Funding. The research work presented in this paper was supported by Grant BR27199433 from the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan

Author contributions. Conceptualization – A.G.; methodology, M.S.; formal analysis – S.O. and A.A.; resources – S.D.; writing – S.O. and A.A.; writing (review and editing) - M.S.; visualization – S.O. and S.D.; supervision – A.G and. M.S.

All authors have read, agreed to release version of a manuscript and signed the Author's right transfer form.

References

1. Winter, C., Kern, F., Gall, D., Latoschik, M. E., Pauli, P., & Käthner, I. (2021). Immersive virtual reality during gait rehabilitation increases walking speed and motivation: A usability evaluation with healthy participants and patients with multiple sclerosis and stroke. Journal of NeuroEngineering and Rehabilitation, 18(1), 68. https://doi.org/10.1186/s12984-021-00848-w
2. Fung, J., Richards, C. L., Malouin, F., McFadyen, B. J., & Lamontagne, A. (2006). A treadmill and motion coupled virtual reality system for gait training post-stroke. CyberPsychology & Behavior, 9(2), 157–162. https://doi.org/10.1089/cpb.2006.9.157
3. Cano Porras, D., Siemonsma, P., Inzelberg, R., Zeilig, G., & Plotnik, M. (2018). Advantages of virtual reality in the rehabilitation of balance and gait: Systematic review. Neurology, 90(22), 1017–1025. https://doi.org/10.1212/WNL.0000000000005603
4. Laver KE, Lange B, George S, Deutsch JE, Saposnik G, Crotty M. Virtual reality for stroke rehabilitation. Cochrane Database Syst Rev. 2025;6:CD008349. https://doi.org/10.1002/14651858.CD008349.pub5
5. Levin MF, Weiss PL, Keshner EA. Emergence of virtual reality as a tool for upper limb rehabilitation. Phys Ther. 2015;95(3):415–425. https://doi.org/10.2522/ptj.20130579
6. Howard MC. A meta-analysis and systematic review of virtual reality rehabilitation programs. Comput Human Behav. 2017;70:317–327. https://doi.org/10.1016/j.chb.2017.01.013
7. Lefeber N, Swinnen E, Kerckhofs E. Virtual reality applications in clinical gait rehabilitation: systematic review. Gait Posture. 2021;86:45–55. https://doi.org/10.1016/j.gaitpost.2021.02.028
8. Shah SH, Karlsen AS, Solberg M, Hameed IA. A social VR-based collaborative exergame for rehabilitation. Virtual Reality. 2023;27(4):3403–3420. https://doi.org/10.1007/s10055-022-00721-8

9. Schalbetter L, Grêt-Regamey A, Gutscher F, Wissen Hayek U. High-fidelity immersive VR environments for gait rehabilitation exergames. Front Virtual Real. 2025;5:1502802. https://doi.org/10.3389/frvir.2024.1502802

10. Lee MC, Chen CC, Pan CT. Multimodal sensor-integrated lower limb exoskeleton with digital twin framework for real-time gait rehabilitation. IEEE Trans Instrum Meas. 2026. https://doi.org/10.1109/TIM.2026.3654715

11. Gil-Agudo Á, Megía-García Á, Pons JL, Sinovas-Alonso I, Comino-Suárez N, Lozano-Berrio V, Del-Ama AJ. Exoskeleton-based training improves walking independence in incomplete spinal cord injury patients: results from a randomized controlled trial. Journal of neuroengineering and rehabilitation. 2023 Mar 24;20(1):36. https://doi.org/10.1186/s12984-023-01158-z

12. Mehrholz J, Thomas S, Werner C. Electromechanical-assisted training for walking after stroke. Cochrane Database Syst Rev. 2020;10:CD006185. https://doi.org/10.1002/14651858.CD006185.pub5

13. Decker G, Hunt D. Proximal iliotibial band syndrome in a runner: a case report. PM&R. 2019 Feb;11(2):206-9. https://doi.org/10.1016/j.pmrj.2018.06.017

14. Gil-Gómez JA, Lloréns R, Alcañiz M, Colomer C. Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation: a pilot randomized clinical trial in patients with acquired brain injury. Journal of neuroengineering and rehabilitation. 2011 May 23;8(1):30. https://doi.org/10.1186/1743-0003-8-30

15. Dollar AM, Herr H. Lower extremity exoskeletons and active orthoses: challenges and state of the art. IEEE Trans Robot. 2008;24(1):144–158. https://doi.org/10.1109/TRO.2008.915453

16. De Rooij IJM, van de Port IGL, Meijer JWG. Effect of virtual reality training on balance and gait ability in stroke patients: systematic review. Phys Ther. 2016;96(12):1905–1918. https://doi.org/10.2522/ptj.20160054

Когнитивтік-қозғалыстық оңалтуға арналған виртуалды шындық негізіндегі 3D ойын жүйесін роботтық экзоскелетпен интеграциялау: 3D VR жүйесінің архитектурасы және жүзеге асырылуы

Өмірбаев С.Ж. [1], Әбдікалық А.М. [2], Дәулетбаев Ш.О. [3*], Шәкенов М.Ж. [4], Ғиният А. [5]

[1] Ғылыми қызметкер, Назарбаев Университеті, Астана, Қазақстан. E-mail: sultan.omirbayev@nu.edu.kz

[2] Ғылыми қызметкер, Назарбаев Университеті, Астана, Қазақстан. E-mail: amina.abdikalyk@nu.edu.kz

[3] Ғылыми қызметкер, Назарбаев Университеті, Астана, Қазақстан. E-mail: shyngys.dauletbayev@alumni.nu.edu.kz

[4] Стратегиялық даму және маркетинг департаментінің басшысы, Балаларды оңалтудың ұлттық орталығы, Астана, Қазақстан. E-mail: me.shakenov@nccr.kz

[5] Басқарма төрайымы, Балаларды оңалтудың ұлттық орталығы, Астана, Қазақстан. E-mail: a.giniyat@nccr.kz

Түйіндеме

Зерттеудің мақсаты: педиатриялық когнитивтік-қозғалыстық оңалтуда қолдануға арналған үш өлшемді виртуалды ойын орталарын төменгі аяқ-қолға арналған роботтық экзоскелет және жүгіру жолы жүйесімен біріктіретін иммерсивті виртуалды шындық негізіндегі оңалту платформасын техникалық тұрғыдан валидациялау.

Әдістері. Басқа тағылатын дисплей негізінде иммерсивті виртуалды орта модульдік қағидат бойынша әзірленді. Платформа мәдени тұрғыдан бейімделген бірнеше интерактивті оңалту ортасын, стандартталған өзара әрекеттесу механизмдерін және жүгіру жолымен синхрондалған қозғалыс жүйесін қамтиды. Виртуалды орта мен төменгі аяқ-қолға арналған роботтық экзоскелет арасында екіжақты байланыс қабаты енгізілді, бұл механикалық қолдау көрсетілетін жүру қозғалысын виртуалды тапсырмалармен үйлестіруге мүмкіндік береді. Оңалту сценарийлері үздіксіз жүруді когнитивтік шешім қабылдау тапсырмаларымен біріктіретін қосарланған тапсырма қағидаты бойынша құрылды. Жүйе қауіпсіздік мониторингі механизмдерін, бейімделетін көмек режимдерін және қозғалыс параметрлерін, тапсырма дәлдігін, навигациялық қателерді және орындалу көрсеткіштерін тіркеуді қамтамасыз етеді. Барлық деректер клиникалық зерттеулер жүргізуге жарамды стандартталған форматта сақталады.

Нәтижесі. Бес интерактивті оңалту ортасы және елуге жуық интерактивті нысан енгізілді. Жүйе жүгіру жылдамдығы мен виртуалды қозғалыстың тұрақты синхрондалуын нөл бүтін оннан екі метрге дейінгі жүру жылдамдығында қамтамасыз етті. Экзоскелеттің көмек көрсету режимдері қозғалыс жағдайына байланысты тұрақты жұмыс істеді. Қауіпсіздік мониторингі қозғалыс процесін үздіксіз бақылауға мүмкіндік берді.

https://doi.org/10.52889/1684-9280-2026-77-1-jto036

Платформа жүру параметрлері, тапсырма дәлдігі, қателер саны және орындалу уақыты бойынша құрылымдалған деректер жиынтығын қалыптастырды.

Қорытынды. Әзірленген виртуалды шындыққа негізделген оңалту платформасы ортопедиялық және нейроортопедиялық бұзылыстары бар балаларды когнитивтік-қозғалыстық оңалту зерттеулерінде қолдануға арналған құрылымдалған және кеңейтілетін шешім болып табылады. Оның модульдік архитектурасы роботтық құрылғылармен қауіпсіз интеграцияны, жеке бейімдеуді және клиникалық зерттеулерге арналған стандартталған деректер жинауды қамтамасыз етеді. Жүйе пилоттық және рандомизацияланған бақыланатын клиникалық зерттеулер жүргізуге дайын.

Түйін сөздер: виртуалды шындық, оңалту, экзоскелет құрылғылары, жүру, қозғалыс дағдылары.

Интеграция виртуальной реальности на основе 3D-игровой среды с роботизированным экзоскелетом для когнитивно-моторной реабилитации: архитектура и реализация 3D VR системы

Омирбаев С.Ж. [1], Абдикалык А.М. [2], Даулетбаев Ш.О. [3*], Шакенов М.Ж. [4], Гинният А. [5]

[1] Научный сотрудник, Назарбаев Университет, Астана, Казахстан. E-mail: sultan.omirbayev@nu.edu.kz

[2] Научный сотрудник, Назарбаев Университет, Астана, Казахстан. E-mail: amina.abdikalyk@nu.edu.kz

[3] Научный сотрудник, Назарбаев Университет, Астана, Казахстан. E-mail: shyngys.dauletbayev@alumni.nu.edu.kz

[4] Руководитель департамента стратегического развития и маркетинга, Национальный центр детской реабилитации, Астана, Казахстан. E-mail: me.shakenov@nccr.kz

[5] Председатель Правления, Национальный центр детской реабилитации, Астана, Казахстан. E-mail: a.giniyat@nccr.kz

Резюме

Цель исследования: разработка и техническая валидация иммерсивной платформы реабилитации на основе виртуальной реальности, интегрирующей трехмерные игровые среды с роботизированным экзоскелетом нижних конечностей и системой беговой дорожки для педиатрической когнитивно-моторной реабилитации.

Методы. Иммерсивная виртуальная среда на основе носимого дисплея была разработана по модульному принципу. Платформа включает несколько культурно адаптированных интерактивных реабилитационных сред со стандартизированными механизмами взаимодействия и синхронизацией движения с беговой дорожкой. Реализован двусторонний интерфейс связи между виртуальной системой и роботизированным экзоскелетом нижних конечностей, обеспечивающий согласованность механически ассистированного шага с виртуальными задачами. Реабилитационные сценарии построены по принципу двойной задачи, сочетающей непрерывную ходьбу с когнитивными заданиями на принятие решений. Система включает механизмы мониторинга безопасности, адаптивные режимы поддержки и регистрацию параметров шага, точности выполнения заданий, навигационных ошибок и показателей завершения задач. Все данные сохраняются в стандартизированном формате для последующего статистического анализа и клинических исследований.

Результаты. Были реализованы 5 интерактивных реабилитационных сред и более пятидесяти интерактивных объектов. Обеспечена стабильная синхронизация скорости беговой дорожки и виртуального движения в диапазоне от ноль целых одна десятая до двух метров в секунду. Режимы поддержки экзоскелета функционировали стабильно в зависимости от условий движения. Мониторинг безопасности позволил осуществлять непрерывный контроль процесса реабилитации. Платформа формирует стандартизированные массивы данных, включающие параметры походки, точность выполнения заданий, количество ошибок и время выполнения.

Выводы. Разработанная платформа виртуальной реальности представляет собой структурированную и масштабируемую основу для исследований в области когнитивно-моторной реабилитации детей с ортопедической и нейро-ортопедической патологией. Модульная архитектура обеспечивает безопасную интеграцию с роботизированными устройствами, индивидуальную адаптацию задач и стандартизированный сбор клинических данных. Система готова к проведению пилотных и рандомизированных контролируемых клинических исследований.

Ключевые слова: виртуальная реальность, реабилитация, экзоскелеты, ходьба, двигательные навыки.

https://doi.org/10.52889/1684-9280-2026-77-1-jto036