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DIGITAL HEALTH SYSTEMS: SMART-SYSTEM FOR REMOTE SUPPORT OF HYBRID E-REHABILITATION SERVICES AND ACTIVITIES

Oleksandr Palagin, Kyrylo Malakhov, Vitalii Velychko, Tetiana Semykopna, Oleksandr Shchurov

The top-priority challenges were faced by the medical rehabilitation system in Ukraine. Particularly important tasks include, first of all, the rehabilitation of patients who have recovered from COVID-19 disease and people with Combat stress reaction. This fact is well understood both by the society and the leadership of the Ministry of Health of Ukraine, which is creating a special working group on this problem. Ukraine has a system of medical and prophylactic institutions designed for psychological and physical rehabilitation of military personnel; these use modern rehabilitation technologies. However, long-term rehabilitation in such centers is not available to everyone. Therefore, the use of telerehabilitation technology for patients with post-traumatic stress disorder and similar disorders in combination with a means of objective control of the functional state is extremely important. One of the most effective solutions in medical rehabilitation assistance is remote patient / person-centered rehabilitation. Rehabilitation also needs effective methods for the "Physical therapist – Patient – Multidisciplinary team" system, including the statistical processing of large volumes of data. Therefore, along with the traditional means of rehabilitation, as part of the "Transdisciplinary intelligent information and analytical system for the rehabilitation processes support in a pandemic (TISP)" in this paper, we introduce and define: the revised and completed basic concepts of the hybrid e-rehabilitation notion and its fundamental foundations; the formalization concept of the new Smart-system for remote support of hybrid e-rehabilitation services and activities; and the methodological foundations for the use of services (UkrVectōrēs and vHealth) of the remote Patient / Person- centered Smart-system. The software implementation of the services of the Smart-system has been developed.

Keywords: Hybrid e-rehabilitation medicine, Smart-system, Rehabilitation, Telerehabilitation, Transdisciplinary intelligent information and analytical system for the rehabilitation processes support in a pandemic (TISP), UkrVectōrēs, vHealth, Ontology engineering, Transdisciplinary research.

Першочергові виклики постали перед системою охорони здоров'я та медичної реабілітації в Україні. До особливо важливих завдань відноситься, у першу чергу, реабілітація хворих, які одужали від COVID-19 та людей з бойовою психічною травмою. Цей факт добре усвідомлюється, як суспільством, так і керівництвом МОЗ України, яке наразі створює спеціальну робочу групу з цієї проблеми. Україна має систему лікувально-профілактичних закладів, призначених для психологічної та фізичної реабілітації військовослужбовців, в яких використовуються сучасні технології реабілітації. Однак, довготривала реабілітація в таких центрах доступна далеко не всім. Тому, застосування технології телереабілітації хворих з посттравматичним стресовим розладом та подібними розладами, в поєднанні з засобами об'єктивного контролю функціонального стану є вкрай важливим. Одним з ефективних рішень в наданні медичної реабілітаційної допомоги є дистанційна пацієнт-центрична реабілітація – гібридна е-реабілітація, яка потребує online-засобів теледіагностики, телеметрії і втручання з орієнтацією на можливості пацієнта, розвинутої Internet-взаємодії, інтелектуальних інформаційних технологій і сервісів, ефективних методів когнітивної підтримки в системі "Реабілітолог – Пацієнт – Мультидисциплінарна команда", статистичної обробки великих об'ємів інформації тощо. Звідси поряд з традиційними засобами реабілітації у складі системи Трансдисциплінарної інтелектуальної інформаційно-аналітичної системи супроводження процесів реабілітації при пандемії TISP з'явилася Smart-система телемедичного супроводження гібридних е-реабілітаційних заходів. Розроблено формальну модель, програмну реалізацію та методологічні засади застосування сервісів (UkrVectōrēs та vHealth) дистанційної пацієнт-центричної Smart-системи надання медичної реабілітаційної допомоги.

Ключові слова: Гібридна е-реабілітація, Смарт-система, Реабілітація, Телереабілітація, Трансдисциплінарна інтелектуальна інформаційно-аналітична система супроводження процесів реабілітації при пандемії (TISP), UkrVectōrēs, vHealth, Онтологічний інжиніринг, трансдисциплінарні дослідження.

Introduction

The methodology of rehabilitation measures in a pandemic has several significant features associated with the unpredictability and high rate of emergence of problems of high complexity, limited communication between the therapist and the patient, the need for high responsiveness of decision-making and their compliance, the scale of the process and the associated need to use scalable operating tools, etc. One of the most effective solutions in medical rehabilitation assistance is remote patient/personal-centered rehabilitation. It requires online monitoring tools, telemetry and interventions focused on the patient's capabilities, developed Internet interaction, intelligent information technologies, and services. Patient / Person- centered rehabilitation also needs effective methods in the "Physical therapist – Patient – Multidisciplinary team" system, statistical processing of large volumes of data, etc. Therefore, along with the traditional means of rehabilitation, as part of the "Transdisciplinary intelligent information and analytical system for the rehabilitation processes support in a pandemic (TISP)" [1] the Smart-system for remote support of hybrid e-rehabilitation services and activities (Smart-system) was developed. Combined with intelligent remote biofeedback [2] devices and effective miniature remote monitoring, telemetry, and recovery devices (embedded systems and wearable devices) [3], such systems hold great promise, as evidenced by worldwide experience as well. That research would not have been possible without the financial support of the National Research Foundation of Ukraine (NRFU) [4]. The project

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"Transdisciplinary intelligent information and analytical system for the rehabilitation processes support in a pandemic (TISP)" won the competition "Science for Human and Social Security" and received grant funding in 2020 – 2021.

The objective of the research described herein is to develop a formal model, software implementation, and the methodological foundations for the use of services of the remote Patient / Person-centered Smart-system for providing medical rehabilitation assistance to patients in a pandemic (i.e., the novel coronavirus disease COVID-19).

Smart-system for remote support of hybrid e-rehabilitation services and activities [5–7] is a complex, integrated, patient / person-centered information subsystem of TISP for the provision of medical care, solving various clinical, organizational, and research tasks in the field of rehabilitation medicine: consultations; remote observation and support of rehabilitation processes and activities; classification, forecasting, and knowledge extraction; research and review of the new domain areas; use of remote communication technologies; elements of artificial intelligence, in particular, ontology engineering [8–12], machine learning [13] and transdisciplinary research [14].

Digital health, Telehealth, Telemedicine: current definitions and trends

Digital health helps ensure patients receive optimal and timely healthcare by connecting them to needed services through telecommunication, remote patient monitoring (RPM), store-and-forward technologies, and mobile health (mHealth). Digital health promotes healthcare access, improves care, and offers patients a level of convenience difficult to obtain with in-person care. A 2018 rapid review by [15] shows Digital health interventions for certain conditions are equally effective as in-person care. As a result of the COVID-19 pandemic, the majority of hospitals worldwide now use elements of Digital health to connect with patients and practitioners who are not onsite. Despite recent policy changes, many barriers remain that hinder the widespread and successful adoption of dHealth technologies.

Variations in Digital health, telehealth definitions and using two distinctly different terms interchangeably [16] (i.e., "telehealth" and "telemedicine") makes it challenging to understand which is the appropriate term and definition. The many definitions for telehealth and telemedicine may create confusion for healthcare professionals when providing telehealth. The various definitions may also increase confusion among state and national legislators when writing laws and policies that govern telehealth. The differences in how telehealth is defined may lead to variations in telehealth reimbursement policies worldwide or at the national level.

Historically, the term "telemedicine" was used to describe the subject of medicine at a distance. The term "telehealth" gained popularity in the 1990s [17]. In 2005, a US federal subcommittee identified both telemedicine and telehealth as key resources to advance patient care [17]. The number of terms used in the field has continued to expand. The need to accurately define emerging terms is timely given the increase in telehealth visits due to the COVID-19 pandemic [18]. Most organizations and agencies consider the terms "telehealth" and "telemedicine" to be distinct. Those that recognize a distinction state that the term "telehealth" is the broader term and "telemedicine" is the component of "telehealth" specific to clinical care.

"Telehealth" is the most used term. The telehealth definitions most commonly refer to the delivery of healthcare at a distance through technology. Some definitions defined telehealth as being a larger umbrella that encompasses more than just direct medical care delivery. In the academic literature [15–17], "telehealth" was the term most used when describing the process of delivering healthcare across a distance. The most cited "telehealth" definitions in the academic literature were from telehealth-related organizations or U.S. federal agencies (e.g., DHHS, HRSA ATA, CMS, WHO, etc.) [19–24]. The World Health Organization WHO definition was cited most often in the academic literature. Some authors developed their own definition by combining various organizational definitions or listing multiple definitions from telehealth-related organizations [24]. The WHO definition is: "Telehealth is the delivery of health care services, where patients and providers are separated by distance."

The term *"Telemedicine"* is the second most used term in the source data and has often been defined as a subset of telehealth. For example, Health Resources and Services Administration HRSA [25] describes telemedicine (the term telehealth includes telemedicine services but encompasses a broader scope of remote healthcare services. Telemedicine is specific to remote clinical services, whereas telehealth may include remote non-clinical services, such as provider training, administrative meetings, and continuing medical education, in addition to clinical services) as being specific to clinical services under the broader umbrella of telehealth, which encompasses nonclinical aspects as components of healthcare. These services include, but are not limited to, administrative meetings, provider training, and patient education. Some organizations, however, use the terms "telemedicine" and "telehealth" interchangeably.

The term *"Virtual care"* occurred infrequently and the scope of it is unclear. The American Telemedicine Association ATA describes virtual care as follows: "Virtual care is so much more than online urgent care; it is healthcare you can access from the comfort and safety of your home. It is all four modes of care; asynchronous, chat, phone, and video visits." [26]. The expanse of what is included in the definition ranges widely from "virtual care" being synonymous with "telemedicine" to "virtual care" going beyond traditional "telehealth" to include self-management tools driven by artificial intelligence.

Digital Health. Many organizations and worldwide agencies use the term "digital health" as a synonym of the terms "telehealth" and "telemedicine;" however, some posit telehealth is under the digital health umbrella. For example, WHO described digital health as, "a broad category encompassing electronic health, mobile health, telehealth and health data, among others." [27]. Digital health is a broad category encompassing electronic health, mobile health, telehealth, and health data, among others. It offers solutions that can strengthen health systems, such as bringing health services directly to people's homes and to underserved communities, helping to map outbreaks of disease, and integrating digital tools that make health care more responsive and productive.

As with the terms “telehealth” and “telemedicine,” discrepancies exist on whether the term “digital health” is an umbrella term encompassing more than direct clinical care or if it is specific to the delivery of care between a clinician and a patient. For example, U.S. Centers for Disease Control and Prevention CDC blog provides a description of the applications of the term “digital health,” stating that “numerous measurement technologies such as personal wearable devices, internal devices, and sensors that could be used to identify health status and help with disease diagnosis and management.” [28]. The same CDC blog lists wearable devices that capture continuous patient data as technologies included under digital health but does not state that the term “digital health” encompasses the terms of “telehealth” and “telemedicine” in its scope or provide an official definition of the term [29]. Frequently, “digital health” is used as a general term that includes direct patient care visits as well as the collection of health data using wearable devices.

Terms related to telehealth, including terms such as *asynchronous*, *synchronous*, *store-and-forward*, *remote patient monitoring*, *remote physiological monitoring*, and *remote therapeutic monitoring*. There is less diversity and more congruency in these ancillary definitions than among the overarching definitions of telehealth, telemedicine, virtual care, and digital health. *“Asynchronous”* [29] refers to not happening in real-time, allowing for a more relaxed schedule, with participants accessing information in their own time during different hours and from multiple locations. In most cases, “asynchronous” is synonymous with “store-and-forward.” Asynchronous, also known as store-and-forward, refers to the use of prerecorded information used to deliver services. The term *“synchronous”* [29] is stated to be the use of live technology to deliver services. *Remote Patient Monitoring* (RPM) can include peripheral medical equipment (e.g., digital stethoscopes, otoscopes, ultrasounds) to conduct a remote evaluation of the patient in addition to the traditional remote monitoring devices (e.g., glucometers, blood pressure monitors, scales) [30]. Remote physiological monitoring is sometimes used interchangeably with RPM. All sources [29, 30] consider asynchronous, store-and-forward, synchronous, and RPM to fall under the umbrella of “telehealth” and/or “telemedicine”. The “*telehomecare*” and “*point-of-care*” (POC) are the new ancillary terms related to telehealth. In [29] POC describes as the remote care needed to allow people with chronic conditions, dementia, or those at high risk of falling to remain living in their own homes. The approach focuses on reacting to emergency events and raising a help response quickly.

The term “eHealth” or Electronic Health is noted to have originated in the business world when terms associated with electronic commerce (e-commerce) started being used to describe various business areas [31]. The [31] publication defines the term “eHealth” as “an emerging field in the intersection of medical informatics, public health, and business, referring to health services and information delivered or enhanced through the Internet and related technologies.”

Telehealth terms are continuously evolving as the field continues to expand. The commonly used terms are “telehealth” and “telemedicine”. The terms “virtual care” and “digital health” are emerging but are not as commonly used compared to telehealth and telemedicine. The term “digital health” was first used in 2017 but has become more common within the academic literature and websites since 2019. In comparison to “virtual health”, the term “digital health” is currently used more often. It can be noted that during the period of this review the use of the term “telehealth” was replaced with “digital health” on the WHO’s website [27]. The term “virtual care” was first presented in 2018 but is not used in a way that would make it distinct from the term “digital health.” Figure 1 conceptualizes the relationship between the terms in a Venn diagram. Conceptually eHealth has been noted to be an umbrella term that includes the subtopics of mHealth, telemedicine, and electronic health records [32, 33]. However, the term eHealth is used less commonly in this umbrella context than the term “digital health.” As such, the term “digital health” is considered an umbrella term above the term “telehealth” and “telemedicine.”

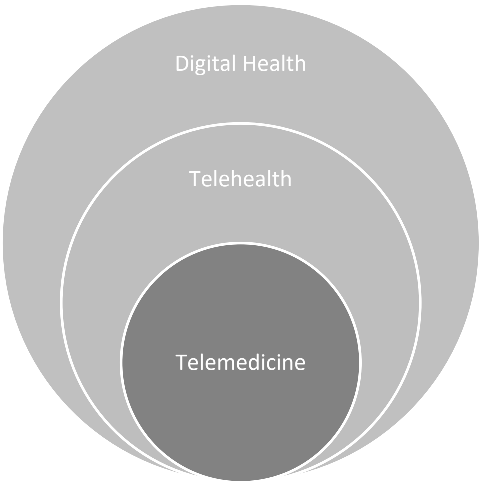

Figure 1. Conceptual Venn diagram of major terms.

Basic concepts of the Hybrid e-rehabilitation notion

The rapid development of telerehabilitation worldwide and the acquisition by this direction of medicine of transdisciplinary connections with various subject areas that go beyond the modern paradigm of e-health, led to the emergence of the most modern type of rehabilitation medicine – Hybrid e-rehabilitation medicine. The Hybrid e-rehabilitation notion (shown in Figure 2) consists of the following fundamental methods, approaches, and technologies (revised and completed in comparison with [IJT, ujprm]):

- *Telecommunication technologies.* This means the delivery of rehabilitation services over telecommunication networks and the internet. Also, this allows patients to interact with providers remotely and can be used both to assess patients and to deliver therapy.
- *Rich Internet Applications (RIA).* These are chiefly the Hospital Information Systems (HIS). A HIS is a comprehensive, integrated information system designed to manage all aspects of a hospital's operation, such as medical, administrative, financial, and legal issues and the corresponding processing of services. Another feature of such systems is the provision of communication between patients and doctors from the multidisciplinary rehabilitation team.
- *Telemetry*. This is a set of technologies that allow remote measurement, and collection and transmission of information about performance indicators (physiological parameters) of the patient's body in real-time or store-in-forward.
- *Wearable devices and Embedded systems*. Wearables may be for widespread use in which case they are just a particularly small example of mobile computing. Alternatively, they may be for special purposes such as fitness trackers or medical devices. They may incorporate special sensors such as accelerometers, heart rate monitors, or on the more advanced side, electrocardiogram (ECG), blood oxygen saturation (SpO_2) monitors and blood pressure monitoring devices. These functions are often bundled together in a single unit, like an activity tracker or a smartwatch like the Apple Watch Series or Samsung Galaxy Gear Sport. Devices such as these are used for physical training and monitoring overall physical health, as well as for alerting to serious medical conditions such as seizures (e.g., Empatica Embrace). Currently, other applications within healthcare are being explored, such as: forecasting changes in mood, stress, and health; measuring blood alcohol content; measuring athletic performance; long-term monitoring of patients with heart and circulatory problems that records an electrocardiogram and is self-monitoring; health risk assessment applications, including measures of frailty and risks of age-dependent diseases; and automatic documentation of care activities.
- *Biofeedback (BF)*. Biofeedback is the process of gaining greater awareness of many physiological functions of one's own body. Biofeedback [2] may be used to improve health, performance, and the physiological changes that often occur in conjunction with changes to thoughts, emotions, and behavior. Recently, technologies have aided with intentional biofeedback. Humans conduct BF naturally all the time, at varied levels of consciousness and intentionality. BF and the biofeedback loop can also be thought of as self-regulation. Some of the processes that can be controlled include brainwaves, muscle tone, skin conductance, heart rate, and pain perception. The essence of BF-method from a technical point of view is computer registration in real-time of certain physiological parameters that are not available for direct human perception (EEG, electrical resistance of the skin, the heart rate, body temperature, etc.) and their transformation into a form natural to humans. The method is based on the principle of translating information in the form of electrical physiological signals received from a human body using special sensors into feedback information in the form of images, natural messages, multimedia, games, and other forms of information and material interaction in each range of values. BF, along with other well-known methods, is included in the list of treatments officially used in medical rehabilitation in Europe, and in the United States alone, BF-methods are implemented in more than 700 clinical centers.
- *Intelligent virtual / personal assistants*. These assistants are the software agents that can perform tasks or services for an individual based on commands or questions. Virtual assistants use natural language processing to match user text or voice input to executable commands. Many such assistants continually learn using artificial intelligence techniques including machine learning and computational linguistics with distributional semantic modeling in vector spaces [13]. Modern software agents of the class of intelligent virtual assistants can interact with each other to perform a certain class of tasks. The term "chatbot" is sometimes used to refer to virtual assistants generally or specifically accessed by online chat. Some virtual assistants are able to interpret human speech and respond via synthesized voices. In particular, within the framework of the project and the TISP system [34], a universal dialogue subsystem (UDS) was developed and implemented within the Physical Medicine and Rehabilitation (PM&R) domain area in the form of a web application and a virtual interlocutor in the "Telegram" service. The developed UDS of TISP system uses the ontology-related approach, in particular, the ontology representations of the White Book on Physical and Rehabilitation Medicine in Europe [35] WB and the International Classification of Functioning, Disability and Health (ICF; ICF, n.d.). The UDS [34] is based on the new technique which assumes the presence of several query templates with each corresponding to a special semantic type of question. Meaningful entities extracted from the user's natural language phrase are substituted into the corresponding query template. For the most suitable query template selection a tree based semantic analysis method is proposed. The method assumes that the frame is shifting through the words list of the phrase, considering on each step one or several words. These words are analyzed to match one of the conditions on the current tree position. The most matching condition determines the following position on the next level of the tree. The process proceeds until there will remain the only option of query template and all the sufficient conditions for the

corresponding semantic type are proved to be observed. Then depending on the selected query template input entities for it are taken from the given positions of the previous consideration.

- *Artificial Intelligence methods and applications for big data processing to knowledge extraction and solving analytical tasks* [36]. For Knowledge Discovery and solving the main analytical tasks, such as classification, diagnostics, or prediction we use the method called Growing Pyramidal Network (GPN) [36]. GPN inductive training is performed on the basis of precedents sets. The result of training is a regularity in the form of a logical function. GPN belongs to the class of statistical methods. Intelligence information search is based on predictive models of distributional semantics. The GPN method and GPN based software has some unique features. These are: search for all possible combinations of values of objects attributes for allocating the most important combinations of attributes' values for building the model of classes of objects; guaranteed finding the most significant combinations of attributes values using the principle of minimal length of the hypothesis description (logical expression); always 100% correct classification of all objects from training set; works with data of any complexity and possibility to discover a regularity however complex it be; and automatic clustering of objects set. In a pyramidal network, the complexity of decision functions is automatically adjusted to the data from the training set, depending on the compactness of the training set. There is no need for a test set to verify the quality of the found logical regularities. In the process of using regularities, the amount of information contained in the logical regularities is counted. If it has changed, then a decision to retrain the system is made. There is high speed recognition of new objects (i.e., constant, not depending on the volume of stored information). If no exact solution found – all possible solutions (Including the decision "I do not know") is presented and ranked according to the confidence level for each. There is an available explanation mode in which there are explained grounds of the decision for each of the recognizable objects. GPN methods powered the clinical decision support subsystem of TISP.
- *Biomedical Robotics and Bionics.* The Biomedical Robotics research focus area is centered on the design, development, and evaluation of medical robotics systems and smart assistive robotic platforms that enhance the physical capabilities of both patients and clinicians via advancements in mechanical design, modeling and control, sensors and instrumentation, computing, and image processing. Core research topics in this area include medical robotics, haptic interfaces, machine learning, soft robotics, robot-assisted surgery and rehabilitation, tissue modeling, human augmentation, biomechanics, and human-robot interaction. Biomedical robotics research innately draws from several disciplines including mechanical, biomedical and electrical engineering, interactive computing, applied physiology, and materials. Key areas of application and translation include feedback-enabled robotic surgery systems, robot-assisted caregiving, macro-meso-micro-scale image-guided surgical interventions, wearable devices for occupational training and injury prevention, and neurointegrated prosthetic devices (also, mathematical modelling and computer simulation of human-exoskeleton systems with energy-efficient actuators, and computer vision and deep learning for autonomous exoskeleton control and decision making during legged locomotion).

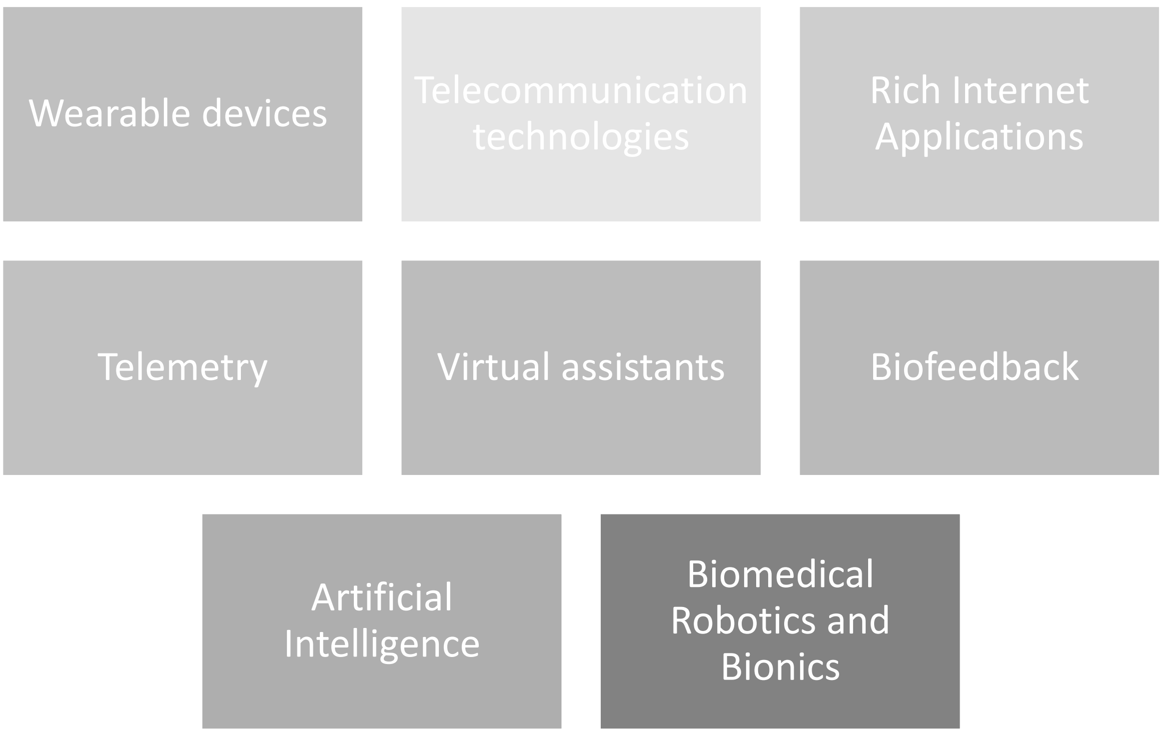

Figure 2. Fundamental Methods, Approaches and Technologies of the Hybrid E-rehabilitation Notion.

The typical representative of systems that implement the concept of the hybrid E-rehabilitation is the TISP system and, in particular, its patient / person-centered information subsystem, a Smart-system for remote support of hybrid e-rehabilitation services and activities. Consider the developed general formalization of the Smart-system.

Formalization concept of Smart-system for remote support of hybrid e-rehabilitation services and activities

The generalized formalization concept of the Smart-system for remote support of rehabilitation activities and services is represented as a three-tuple *S* using the revised formalism given in [5, 6, 11]:

$$S = \langle D, F, E \rangle \tag{1}$$

Where:

S – is the Smart-system for remote support of rehabilitation activities and services (subsystem of TISP). Processes of smart system are described analytically by means of [37].

D – is a set of web services (RIA) and desktop applications that are available for usage in the Smart-system *S*:

$$D = \sum_{j=1}^{k} Z_{Tj} \tag{2}$$

Where:

Z_{T_j} – is a web service or desktop application that implements specific algorithms, processes, and functions of the Smart-system S ($j = \overline{1,k}, k \in \mathbb{N}, k$ – the number of developed web services and desktop applications that are part of the Smart-system *S*).

$F = S{:}\left\{C_i \middle| i = \overline{1,n}\right\}_{n \in \mathbb{N}}$ – is a set of functions, the functional filling-up of the Smart-system *S*, each function is the result of coordination and interaction of the Smart-system *S* elements.

$C_i \subseteq D, C_i = \left\{D_y \middle| y \geq 1, y \leq m\right\}_{y \in \mathbb{N}, m \in \mathbb{N}}$ – is a subset of web services and desktop applications that are required to implement the *j*-th function of Smart-system *S*. The formation of this subset allows creating personalized pipelines and scenarios for using the developed web services and desktop applications (as well as the use of additional external software), which enables more flexibly in use of the services of the Smart-system for PM&R doctors. The formation of such pipelines and scenarios is beyond the scope of this article and should be considered separately.

$E = \{prl, mid, os\}$ – is a set of elements (represented as layers) that combine into the Cloud-integrated Environment (CIE);

prl – physical resource layer represents physical hardware and facility resources;

mid – middle layer (using in the concepts of cloud service orchestration model [11, 38] represents resource abstraction and control layer. It is supposed to use OpenStack software platform;

os – operating system layer represents guest operating system. It is supposed to use Ubuntu server with LXDE (abbreviation for Lightweight X11 Desktop Environment) desktop environment or Xfce desktop environment. web services (RIA) and desktop applications runs on the operating system layer – $Z_{T_j} \in os$;

At the current stage of development, the Smart-system includes various technologies, web services, and desktop applications, in particular:

$$\sum_{j=1}^{7} Z_{T_j} = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7\} \tag{3}$$

Where:

T_1 – *Remote consulting service* – Smart-system's telemedicine module (which provides online video and audio communication) using modified open-source software Jitsi Meet [39].

T_2 – *Digital doctor's office* of specialized medical care service, in particular the PM&R doctors. In the personal digital office, there are services for managing online appointments, including video consultations, personal doctor's and patient's profiles, fiscal management, a calendar for scheduling and planning consultations, access to the electronic health records (i.e., patient's profiles and health history), and a module for carrying out electronic advisory conclusions on the results of the video consultation.

T_3 – *Service for automated processing and integration of all basic workflows* of a medical institution for interaction between an administrator, a doctor, and a patient.

T_4 – *Collaborative service* for the creation and use of file-sharing and exchange services, in particular, for interacting and exchanging medical digital images via Digital Imaging and Communications in Medicine (DICOM). DICOM is the standard for the communication and management of medical imaging information and related data. DICOM is most used for storing and transmitting medical images enabling the integration of medical imaging devices such as scanners, servers, workstations, printers, network hardware, and picture archiving and communication systems (PACS) from multiple manufacturers. It has been widely adopted by hospitals and is making inroads into smaller applications such as dentists' and doctors' offices. DICOM incorporates standards for imaging modalities such as radiography, ultrasonography, computed tomography, magnetic resonance imaging, and radiation therapy. DICOM includes protocols for image exchange (e.g., via portable media such as SD cards), image compression, 3-D visualization, image presentation, and results reporting.

T_5 – *UkrVectōrēs* [40] web service. This is an NLU-powered toolkit for knowledge discovery, classification, diagnostics, and prediction – an entities similarity tool. You can think about UkrVectōrēs as a kind of "cognitive-semantic calculator." The online toolkit UkrVectōrēs covers the following elements of distributional analysis [13]: calculates semantic similarity between pairs of words; finds words semantically closest to the query word; applies simple algebraic operations to word vectors (addition, subtraction, finding average vector for a group of words and distances to this average value); draws semantic maps of relations between input words (it is useful to explore clusters and oppositions, or to test your hypotheses about them); gets the raw vectors (arrays of real values) and their visualizations for words in the chosen model; downloads default models; and uses other prognostic models distributive semantics freely distributed, by adjusting the configuration file.

T_6 – *vHealth Electronic Library service* [41]. This is a distributed information system that allows you to store, use and share various collections of electronic documents (video and audio content) of arbitrary domain areas for distance learning of patients and their relatives, in particular, a rehabilitation complex of exercises and activities.

Consider in detail some services and applications developed according to the generalized formalization concept of the Smart-system for telemedicine support of rehabilitation measures, in particular, UkrVectōrēs and vHealth services.

T_7 – *knowledge-oriented digital library/repository of scientific publications*. Nowadays, numerous applications and tools are known that implement information retrieval technologies in various text sources in accordance with specified parameters. Moreover, the search results are provided to the user for each search parameter individually and not related to each other. And the application of Semantic Web technologies for the purpose of multi-parameter and related information retrieval in various sources in Ukraine is at the initial stage of development. A separate problem is the multimedia presentation of search results and their comparison with the conceptual structure of the domain of interest (Knowledge Domain) with the goal of extracting new knowledge. From this point of view, it is relevant for scientific research to process the scientific publications of one author, authors of a scientific unit and the academic institute, using the Semantic Web technologies, multimedia presentation of information, and effective support for the process of extracting new knowledge.

Consider in detail some services and applications developed according to the generalized formalization concept of the Smart-system for telemedicine support of rehabilitation measures, in particular, UkrVectōrēs and vHealth services.

UkrVectōrēs – an NLU-powered tool for knowledge discovery, classification, diagnostics, and prediction

The distributed numerical feature representations of words (word embeddings) and word vector space models, as a result, are well established in the field of computational linguistics and have been here for decades, see [42] and [13] for an extensive review. However, recently they received substantially growing attention. Learning word representations lies at the very foundation of many natural language processing (NLP) tasks because many NLP tasks rely on good feature representations for words that preserve their semantics as well as their context in a language.

The network service UkrVectōrēs computes the semantic relations (similarity) between the entities of the Ukrainian language within the selected distributional semantic model of the vector representation of entities (entities embeddings). UkrVectōrēs is a natural language distributional analysis and distributional semantic modeling web service (toolkit), a natural language research technique based on the study of the environment (distribution), individual entities in the text without the full lexical or grammatical meanings of these entities. In the general case, distributional analysis, and distributional semantic modeling [13] use, base, and examine the essence of a natural language, such as words or phrases. Within the framework of this method, an ordered set of universal procedures is applied to texts in natural language, which makes it possible to single out the basic units of the language (phonemes, morphemes, words, phrases), to classify them, and to learn the relation of semantic similarity between them.

The network service UkrVectōrēs is a tool that allows exploring the semantic relationships between entities in the framework of predictive models of distributional semantics (PMDS), using an open-source software library genism (Genism, n.d.) for processing and mathematical modeling of the natural language (including an application programming interface for different algorithms such as Word2vec, fastText, etc.). The user can choose one or several carefully prepared predictive models of distributional semantics (or use other models of vector representation for words of the Ukrainian language) learned on various text corpora, in particular, the WB [35] dataset.

The UkrVectōrēs service covers the following elements of the distributional semantic analysis / modeling:

- computation of semantic similarity between pairs of entities (words) within the selected PMDS;
- computation of the entity closest to a given one within the selected PMDS (computation of semantic associates). In distributional semantics, words are usually represented as vectors in a multi-dimensional space of their contexts. Semantic similarity between two entities is then calculated as a cosine similarity between their corresponding vectors; it takes values between *-1* and *1* (usually only values above *0* are used in practical tasks). *0* value roughly means the entities lack similar contexts, and thus their meanings are unrelated to each other. *1* value means that the entities' contexts are identical, and thus their meaning is quite similar;
- applying simple algebraic operations to entity vectors (addition, subtraction, finding average vector for a group of entities and distances to this average value) within the selected PMDS;

- generation of the semantic maps (using the open-source software toolkit TensorFlow) of relations between input entities (it is useful to explore clusters and oppositions, or to test your hypotheses about them);
- using other freely shared PMDS via special configuration file.

Let us consider the methodology of a user experience with the graphical user interface of the UkrVectōrēs single-page application, in particular, for the distributional semantic analysis of natural language texts. Requirement analysis for this problem domain was done by the approach [43].

Computation of the semantic associates for a given entity (word) within the selected distribution-semantic model. To use this function, you need to:

1. Open the graphical user interface (GUI) of the UkrVectōrēs Single Page Application (SPA) using the current version of Google Chrome, Mozilla Firefox, or Microsoft Edge web browser. To do this, enter the following link in the address bar of the web browser: https://ukrvectores.ai-service.ml/ (the link may differ, it depends on the deployment features of the UkrVectōrēs service) and select the Semantic Associates operation mode in the main menu, as shown in Figure 3.
2. Using the drop-down list of the select component named Models (in Ukrainian – Моделі) in Figure 4, choose the desired distributional semantic model, within which the computation of semantic associates will be carried out (by default the neural vector model for words representation "White Book" is used (using the "White Paper on Physical and Rehabilitation Medicine in Europe" dataset), word2vec word embeddings algorithm with the dimension of 500d. The entity is a word, lemmatized, reduced to lower case. Hyperparameters of word2vec are: *-size 500 -negative 5 -window 5 -threads 24 -min_count 10 -iter 20*).
3. In the field of the input component named "Enter the word lemma," specify the desired word lemma for which you want to compute semantic associates (for example, rehabilitation (in Ukrainian – реабілітація), as shown in Figure 3) and press the "Enter" key or the "Compute" button.
4. Semantic Associates will be displayed on the screen as shown in Figure 3 (by default, the first 100 associates for decreasing the cosine similarity coefficient are displayed) for the given lemma of the word rehabilitation (in Ukrainian – реабілітація) within the selected distributional semantic model "White Book".
5. Using the "Entity" (in Ukrainian – "Сутність") element, the user can choose to display the semantic associates alphabetically as shown in Figure 5.

Using the "Cosine similarity" (in Ukrainian – "Косинусна близькість") element, the user can choose to display the semantic associates by the cosine similarity coefficient (by increasing or decreasing) as shown in Figure 6.

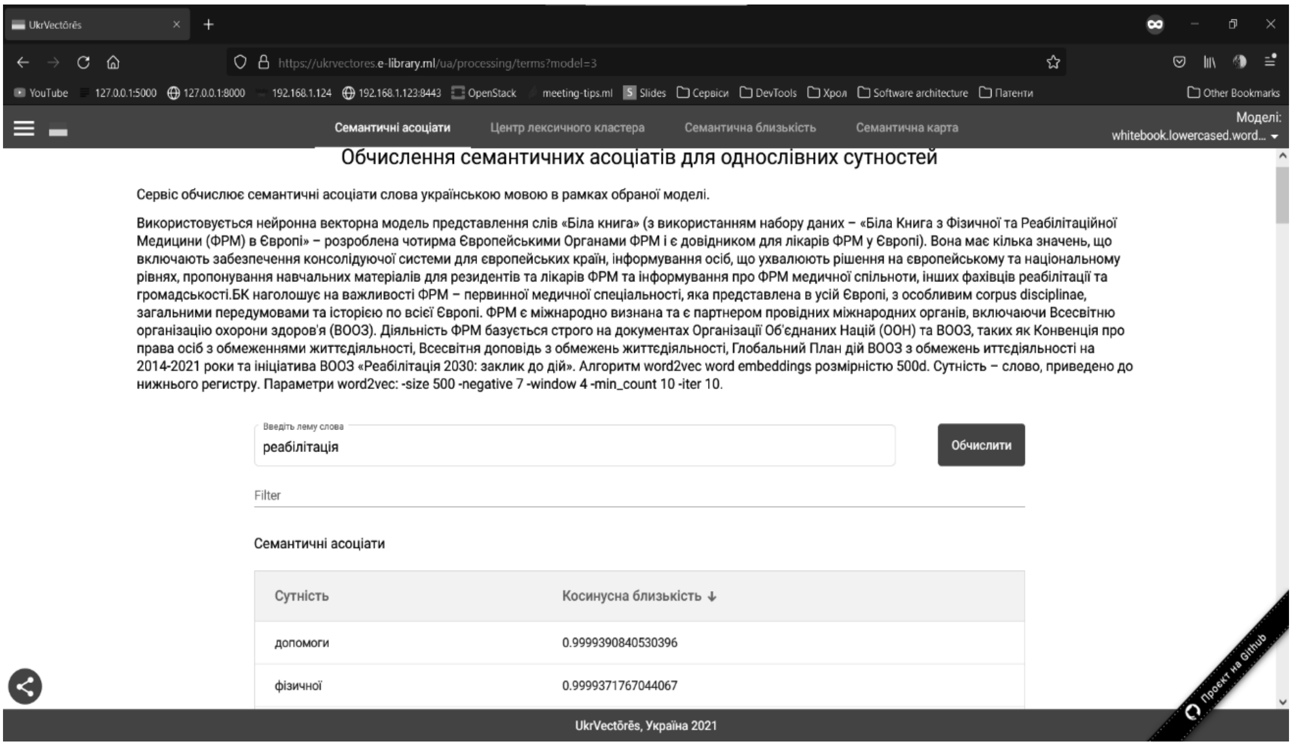

Figure 3. GUI of the UkrVectōrēs SPA Service ("Semantic Associates" Mode).

Generation of semantic maps (using the open-source software toolkit TensorFlow, namely TensorBoard) of relations between words within the selected distributional semantic model. To use this function, you need to:

1. Open the GUI of the UkrVectōrēs SPA using the current version of Google Chrome, Mozilla Firefox, or Microsoft Edge web browser. To do this, enter the following link in the address bar of the web browser: https://ukrvectores.ai-service.ml (the link may differ, it depends on the deployment features of the UkrVectōrēs service) and select the Semantic map mode in the main menu, as shown in Figure 7.

2. Using the drop-down list of the select component named Models (in Ukrainian – Моделі) in Figure 7, choose the desired distributional semantic model, within which the computation of semantic associates will be carried out (by default the neural vector model for words representation "White Book" is used (using the "White Paper on Physical and Rehabilitation Medicine in Europe" dataset), word2vec word embeddings algorithm with the dimension of 500d. The entity is a word, lemmatized, reduced to lower case. Hyperparameters of word2vec are: -size 500 -negative 5 -window 5 -threads 24 -min_count 10 -iter 20).
3. An example of visualization of the semantic associates of the lemma of the word "rehabilitation" (in Ukrainian – реабілітація) is shown in Figure 8.

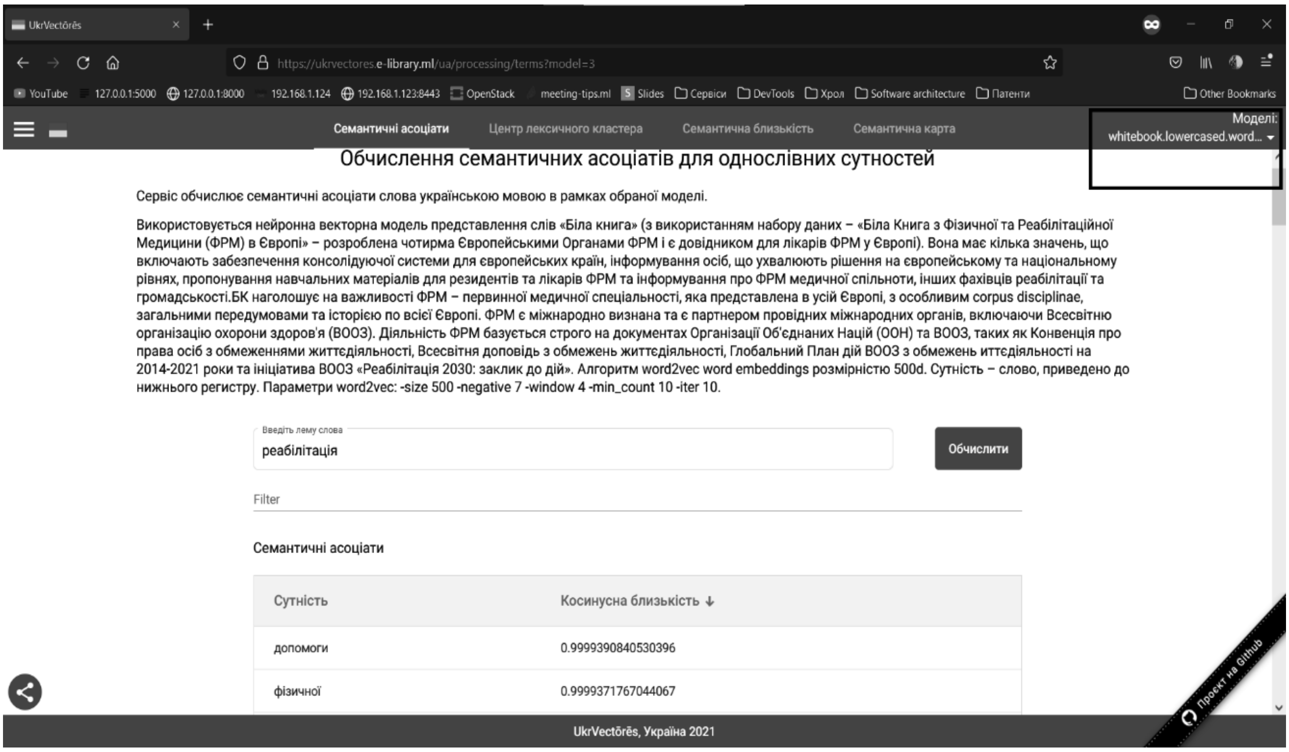

Figure 4. GUI of the UkrVectōrēs SPA Service ("Semantic Associates" Mode, the Select Component Called "Models").

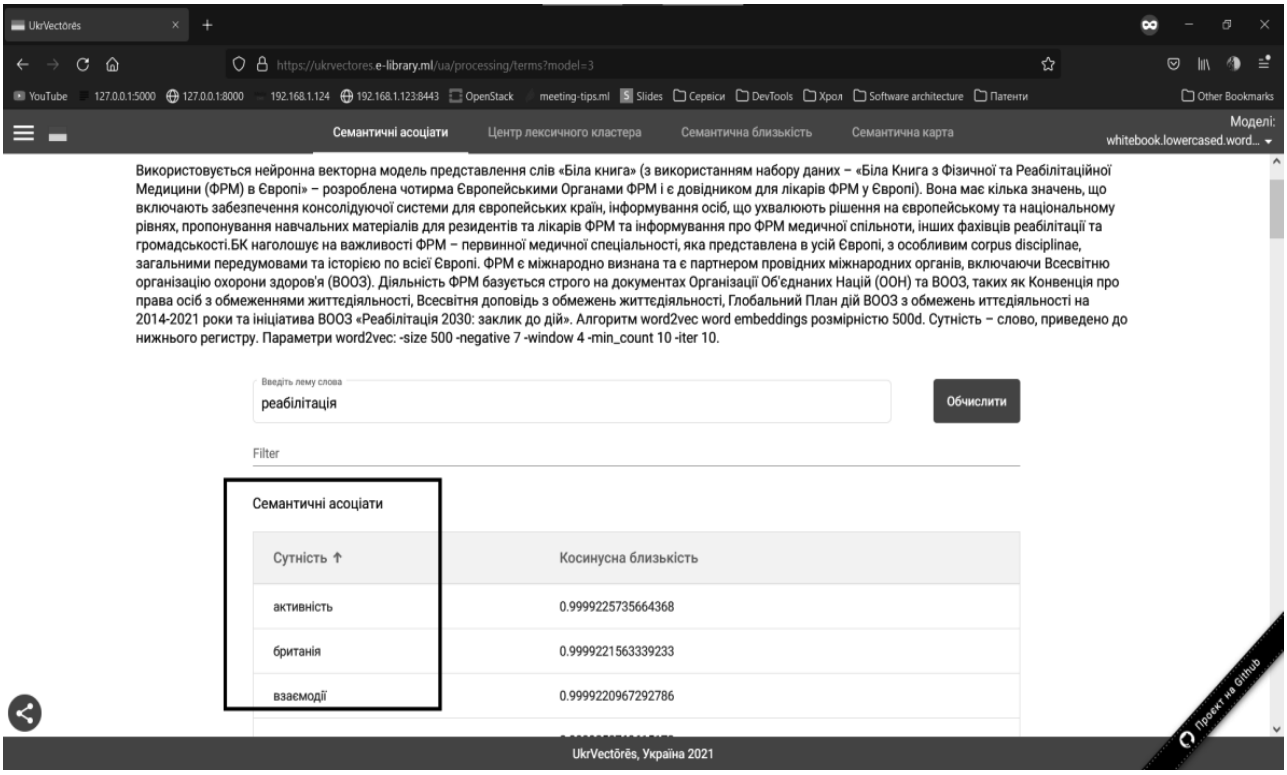

Figure 5. GUI of the UkrVectōrēs SPA Service ("Semantic Associates" Mode, the "Entity" Element).

The compilation & deployment technologies, and more detailed description of the source code of the UkrVectōrēs service, as well as the methodology for training the distributional semantic model of the vector representation of entities (using the dataset - "White Paper on Physical and Rehabilitation Medicine (PRM) in Europe"), are available in [40]. Currently, the most recent version of the UkrVectōrēs service is available at https://ukrvectores.ai-service.ml/ and is free for use in R&D and teaching purposes.

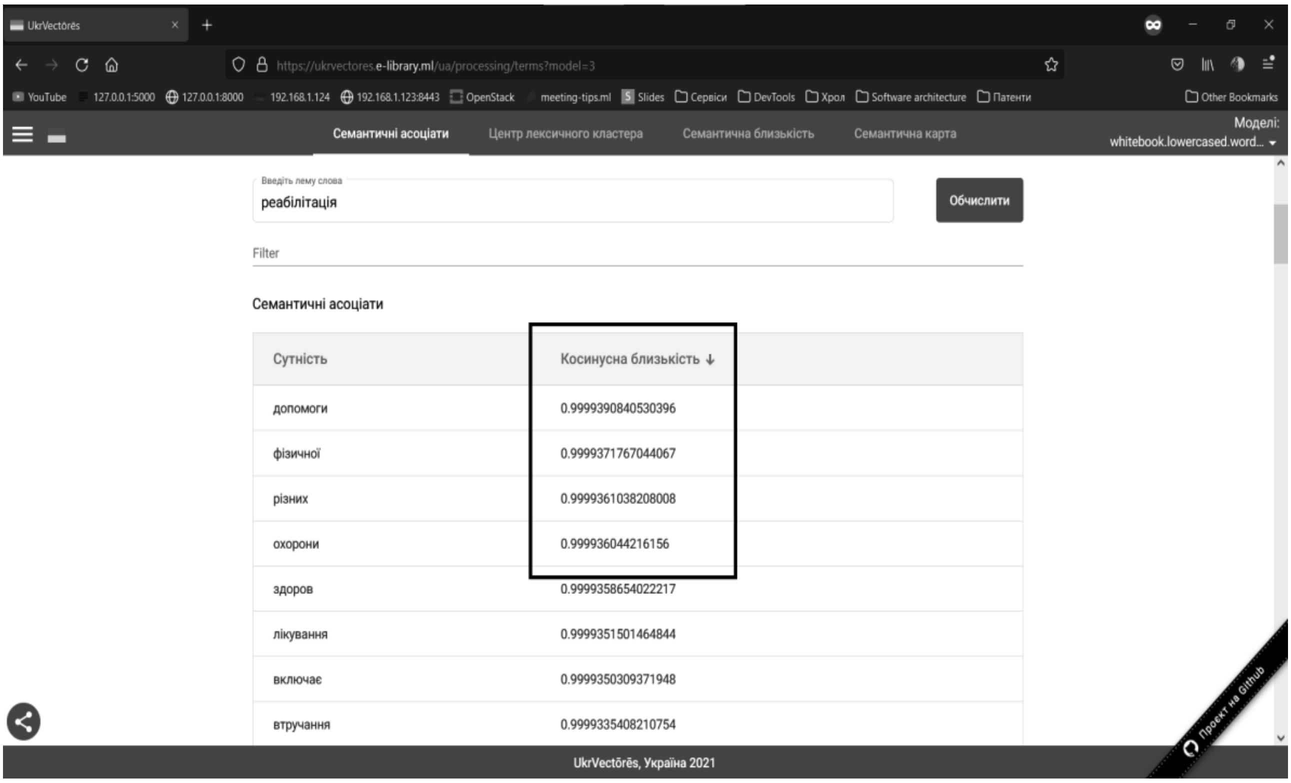

Figure 6. GUI of the UkrVectōrēs SPA Service ("Semantic Associates" Mode, the "Cosine Similarity" Element).

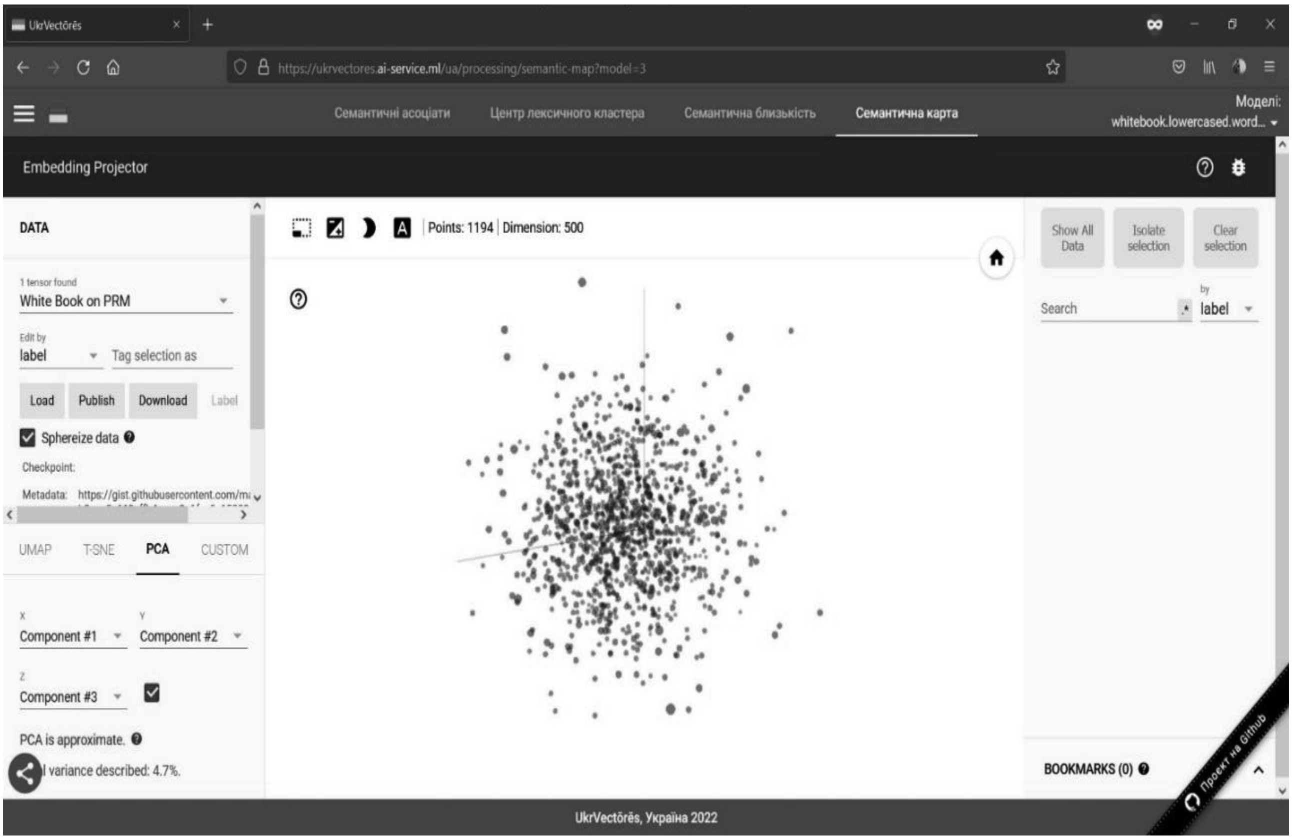

Figure 7. GUI of the UkrVectōrēs SPA Service ("Semantic Map" Mode).

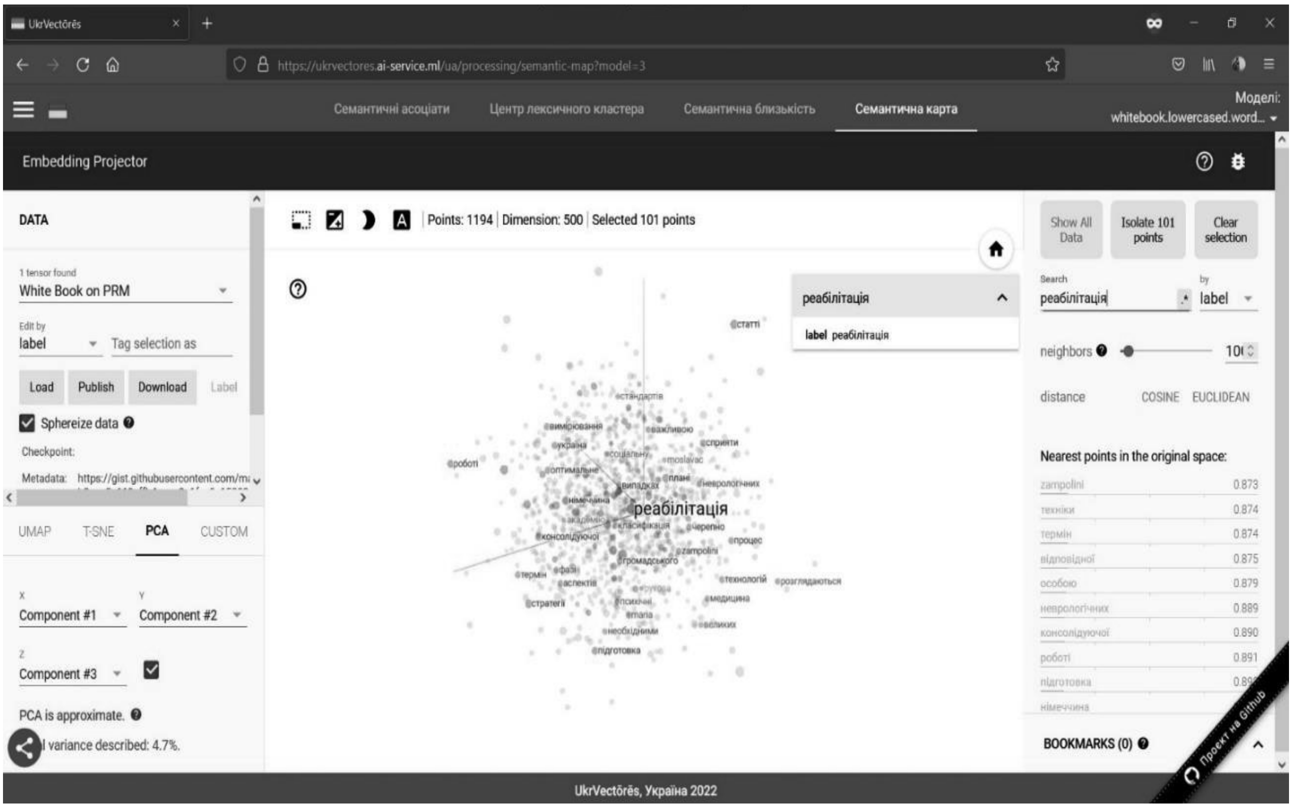

Figure 8. Visualization of the Semantic Associates of the Lemma of the Word in Ukrainian – реабілітація.

vHealth – the digital library of media content

The digital library of media content of the TISP Smart-system subsystem - the vHealth service [41] is a distributed information system that allows the storage, use, and sharing of various collections of electronic documents (video and audio content) of arbitrary domain areas, for distance learning of patients and their relatives, in particular, a rehabilitation set of exercises.

One of the main tasks and purposes of the vHealth service is the integration of information resources and efficient navigation within them. Integration of information resources is their unification to use different information while preserving its properties, presentation features, and the ability to process it. The pooling of resources can occur both physically and virtually. However, at the same time, such a combination should provide the user with the perception of the necessary information as a single information space: an electronic library should ensure work with databases and high efficiency of the information search. Effective navigation in the electronic library is the ability of the user to find the information of interest to them in all available information space with the greatest completeness and accuracy at the least effort. To solve this problem, the vHealth service uses smart search based on predictive models of distributional semantics.

The vHealth service has the following features:

- complete control over media content and user data;
- support for multiple publishing workflows: public, private, unlisted, and custom;
- types of multiple media support: video, audio, image, pdf (and docx in future releases);
- multiple media classification options: categories, tags, and custom;
- intelligent information search in real time based on the predictive models of distributional semantics (lexical, symbolic, and attribute search);
- playlists for audio and video content: create playlists, add, and reorder content;
- SPA responsive design: including light and dark themes;
- advanced users' management: allows self-registration, invite only, closed;
- configurable actions: allows download, add comments, add likes, dislikes, report media;
- enhanced video player: customized video.js player with multiple resolution and playback speed options;
- multiple transcoding profiles: sane defaults for multiple dimensions (240p, 360p, 480p, 720p, 1080p) and multiple profiles (h264, h265, vp9);
- chunked file uploads: for pausable/resumable upload of content;
- logging of the user's session with the system with the ability to switch to each of the previously existing system states;
- manipulating the structure of the description of the media content object;
- support of the appliance of hypertext and hypermedia links, which provides the user with a quick transition from an object or its element to another interrelated object or element.

The compilation, deployment, and a more detailed description of the source code of the vHealth service, as well as the methodology of user interaction with the GUI of the vHealth application, require a separate review and is beyond the scope of this article. Currently, the most recent version of the vHealth service is available at https://vhealth.ai-service.ml/ and is free for use for R&D and teaching purposes. To start working with the vHealth service, you need to be an authorized user (log in), so the demo account was created to demonstrate how the service works. You can log in using the login and password of the demo profile account (login: demouser; password: JyMyuC6nMdD494T).

Conclusion

The purpose of our research was to develop a formal model, software implementation, and the methodological foundations for the use of services of the remote Patient / Personal-centered Smart-system for providing medical rehabilitation assistance to patients in a pandemic.

In this paper, we introduced and defined:

- the basic concepts of the new Hybrid E-rehabilitation notion and its fundamental foundations;
- the formalization concept of the new Patient / Person-centered Smart-system for remote support of rehabilitation activities and services;
- the methodological foundations for the use of services (UkrVectōrēs and vHealth) of the remote Patient / Person-centered Smart-system.

The software implementation of the services of the Smart-system for remote support of rehabilitation activities and services has been developed, in particular:

- the digital library of media content of the telerehabilitation subsystem of TISP – the vHealth service;
- the UkrVectōrēs service - NLU-powered network tool for knowledge discovery, classification, diagnostics, and prediction.

The research results were presented by our team on the All-Ukrainian forum “Ukraine 30: Education and Science” in section – “Big data Ukraine platform.” Also, the research results (in teleconference and offline) were presented during the workshop “Digital services and devices for rehabilitation measures support.”

Further research

This study can be extended by future research in several directions, both in theory and in practice. Further research is also planned in the definition and application of efficient mathematical methods for big data analysis; modeling and creating scenarios (workflows) for predicting and optimizing the entire complex of rehabilitation procedures and their routing using system tools; and technologies, and experience in the development of rehabilitation systems and complexes that have already been tested by our team.

In a future study, our teams plan to implement HIS to optimize the time spent by specialists of the multidisciplinary team in the use of ICF in the rehabilitation of cancer patients (including breast cancer). Further research will aim to determine and apply effective mathematical methods of big data analysis, modeling and developing of prediction scenarios, and optimization of the full set of rehabilitation procedures and their routing. This will employ tools already tested in the team system, technologies, and experience in developing rehabilitation systems.

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About the authors:

Palagin Oleksandr Vasylovych,
Doctor of Sciences, Academician of National Academy of Sciences of Ukraine,
Deputy director of Glushkov Institute of Cybernetics,
head of department 205 at Glushkov Institute of Cybernetics,
590 Ukrainian publications,
101 International publications,
H-index: Google Scholar – 20,
Scopus – 9,
http://orcid.org/0000-0003-3223-1391.

Velychko Vitalii Yuriiovych,
Doctor of Sciences, assistant professor, Senior researcher,
80 Ukrainian publications,
31 International publications,
H-index: Google Scholar – 11,
Scopus – 2,
http://orcid.org/0000-0002-7155-9202.

Malakhov Kyrylo Serhiiovych,
Research Fellow,
47 Ukrainian publications,
7 International publications,
H-index: Google Scholar – 6,
Scopus – 1,
http://orcid.org/0000-0003-3223-9844.

Semykopna Tetiana Viktorivna,
Research fellow,
27 Ukrainian publications,
3 International publications,
H-index: Google Scholar – 4,
https://orcid.org/0000-0002-4116-0567.

Shchurov Oleksandr Serhiiovych,
Junior research fellow,
11 Ukrainian publications,
4 International publications,
H-index: Google Scholar – 4,
Scopus – 1,
http://orcid.org/0000-0002-0449-1295.

Place of work:

Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine,
40 Glushkov ave., Kyiv, Ukraine, 03187,
tel.: (+38) (044) 526 3348
email: palagin_a@ukr.net

Прізвища та ініціали авторів і назва доповіді українською мовою:
О.В. Палагін, К.С. Малахов, В.Ю. Величко, Т.В. Семикопна, О.С. Щуров
Система цифрового здоров′я: SMART-система
телемедичного супроводження гібридних
Е-реабілітаційних заходів

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O.V. Palagin, K.S. Malakhov, V.Yu. Velychko, T.V. Semykopna, O.S. Shchurov
Digital health systems: SMART-system for remote
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