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Rehabilitation systems for physically disabled patients: A brief review of sensor-based computerised signal-monitoring systems.

Nizam Uddin Ahamed[1], Kenneth Sundaraj[1], Badlishah Ahmad[1], Matiur Rahman[2], Md. Asraf Ali[1], Md. Anamul Islam[1] and Rajkumar Palaniappan[1]

[1]AI-Rehab Research Group, Universiti Malaysia Perlis (UniMAP), Kampus Pauh Putra, 02600 Arau, Perlis, Malaysia
[2]College of Computer Science and Information System, Najran University, Kingdom of Saudi Arabia.

Abstract

This brief review addresses the existing systems and challenges and provides future recommendations on computer- and biosensor-assisted rehabilitation systems for physically disabled patients. We further list the types of sensors, technical issues, and different software and hardware technologies that are currently used in rehabilitation systems to make the whole process dynamic and real-time. The review focused on 36 consolidated studies that were found using the following keywords: rehabilitation system, sensor, and computer. The electronic databases PubMed, Scopus, and Google Scholar were searched for relevant articles that were published from 2007 through 2012. These published articles included discussion of several biosensors, automated rehabilitation systems, and the application of these systems in the affected body parts of the individuals. We found that 54 types of biosensors have been used for real-time and computer-assisted rehabilitation systems. The findings suggest that there are still some body parts (such as the muscle tendons area and abdomen) and application areas (e.g., post- and pre-pregnancy) that have not yet been targeted by biosensor-supported medical rehabilitation systems aided by suitable hardware, software, and other assistive technologies.

Keywords: Biosensor, Signal, Computer, Hardware, Rehabilitation, Software, Disable Patients.

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Introduction

Recent years have seen the advances of a number of automated and semi-automated systems to support physiotherapy and rehabilitation [1]. Automatic rehabilitation is a type of therapy that aims to partially or totally recover the neurocognitive function and motor abilities of a patient. Thus, the affected person needs a perfect machine-controlled recovery system that is easy to operate, can provide the correct result without delay, and is cost effective for the users. As a result, the whole process can help the patients return to their previous stage promptly. Due to the fast advances in medical technology worldwide, rehabilitation systems are currently used by patients after a major operation, chronic pain, sensory loss, stroke, unpredicted pain, severe accident, orthopaedic anarchy, brain injury, Parkinson's disease (neurological disorder), psychological disorder, and sports-related injury and by older individuals [2, 3]. Briefly, the cardiopulmonary, neurological, orthopaedic, paediatric, and integumentary (skin and related organ) systems are the most essential and common areas in the human body that are subjected to rehabilitation treatment [4]. The full recovery process may be accomplished after several days of daily rehabilitation, and the duration of the program depends on the patient's health [5]. To monitor their progression, end users need vast and deep experiences with the rehabilitation devices that can aid a patient's quick recovery.

A system for biosignal based device applications contains a biosignal sensor (e.g. biosensor) or multiple biosensors (e.g. multiple biosensors for EEG detection, or multiple biosensors that can each detect different types of biosignals), a biosignal processing unit, the apparatus (hardware), and a software application(s) that operate the biosignal information for different applications [6]. Biosensors are analytical devices that have two components: one is a bioreceptor and the other is a transducer. The bioreceptor is a biomolecule that recognises the target analyte, and the transducer converts the recognition event into a measurable signal [7]. In short, a biosensor converts a biological response into an electrical signal. There are several supported mechanisms that are used to actively monitor the rehabilitation process in real time. Physiological sensors are one of the fundamental parts of biosignal processing, and are thus important in automatic rehabilitation systems because they offer considerable advantages in the clinical and biomedical industry, such as specificity, small size, faster response, and low cost [8]. .

Until now, several authors have discussed, developed and reviewed rehabilitation systems with different procedures. For example, Silvia *et al.,* studied a novel mechatronic-dependent neurorehabilitation system that can evaluate the post-stroke functional recovery through whole-body isometric force measurements [9]. Majdalawieh *et al.,* explained the relationship between biomedical signals and rehabilitation engineering using EMG, EEG, neural network, wavelet transforms, and Fourier transforms [10]. In other studies, some scholars have reviewed home-based telerehabilitation systems for stroke patients. These studies focused on a few number of biosensors and applications of these biosensors in physical recovery systems and compared with the results obtained with the different sensors/applications. Pantelopoulos et al. studied the uses of wearable biosensors for health monitoring systems [11, 12]. Katherine *et al.,* reviewed the clinical aspects of robotic assistive technology and human-robot interaction for rehabilitation but did not clearly mention the biosensors used in the study [13]. However, we did not find any previously reported work in which the authors summarised the biosensors, computer, hardware, and software used in various rehabilitation systems and the applicability of the different rehabilitation devises.

This review paper is organised as follows. In the Methods section, details on the overall searching process that was used to obtain the results are discussed, including the different keywords, the online databases, and the time frame. The biosensors, hardware, software, and computer process models that were found in the literature are summarised and presented briefly in the Results section through the use of a table. The Discussion section presents an overall discussion in which the new finding related to the development of new biosensors that may aid recovery systems are presented. The Conclusion section recaps the review paper.

Methods

A systematic search of the existing literature was performed using a combination of the keywords “rehabilitation system”, “sensor”, and “computer” to find the related studies published between 2007 and 2012 in the following electronic databases: PubMed, Scopus, and Google Scholar. During the article search, the relevant titles and abstracts were analysed. If the expected criterion was matched, the full text was then reviewed. The inclusion criteria were the following: (1) any rehabilitation and/or assistive system that is assisted by a biosensor and computer, (2) systems developed for the human body, and (3) papers written in English. The exclusion criteria were the following: (1) rehabilitation systems assisted by a robot or other devices (except a computer, PDA, smart phone, mobile etc.), (2) no information on the biosensor/biosignal, and (3) not a real-time system for monitoring the signals.

Results

Literature search results

The three electronic databases contained 2,140 articles with the keywords “rehabilitation system”, “sensor” and “computer”. After the articles from the three databases were collected, all of the duplicate articles were removed to obtain 1,200 articles. All of the articles were then filtered to determine whether the systems are automatic, real-time, and assisted by a computer and biosensor, which resulted in a total of 165 articles. Then, 129 articles were rejected because these did not fulfil the review criteria. As a result, 36 articles went used in the analysis.

Rehabilitation systems

The 36 articles in which the researchers developed computerised rehabilitation systems are presented in Table 1. Of these systems, six were developed for different muscles [14-19], five were developed for cardiac patients [8, 20-23], thirteen were developed for stroke patients [24-36], eight were developed for upper limbs [5, 37-43], two were developed for chronic illness and neurolocomotor [44, 45], one was developed for hemiplegia [46], and one was developed for ankle and spinal cord injury [47].

Applied Sensors

The wide range of study designs included and reflected in this review paper incorporated various types of biosensors. Researchers mainly used electromechanical, electrical, optical, and thermal biosensors, acoustic signal transducers, or mass-sensitive biosensors to develop rehabilitation systems. In this systematic review, a total of 54 types of biosensors were used for rehabilitation systems; these are itemised in Table 1. Some of the most commonly used biosensors that were applied in rehabilitation systems are electromyography (EMG), galvanic skin response (GSR) Electrocardiography (ECG), electroencephalography (EEG), grip sensors, inertial measurement units, orientation, and torque. In addition, most of the developed systems used EMG for musculoskeletal rehabilitation. However, all the biosensors and their applications are listed in Table 1. Figure 1 represents a graphical view of the EEG signal recording of a child brain.

Software and hardware

Computer-assisted rehabilitation systems are significantly less labour-intensive compared with conventional manually assisted-movement therapy systems [4]. We discovered that a total of 36 computer-assisted rehabilitation systems have been developed and are described in the literature.

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***Table 1**. An overview of biosensor-assisted automatic rehabilitation systems*

Author [ref]	Rehab area	Sensor	Software	Hardware
Burns *et al.*, [14]	Biceps and triceps	EMG, accelerometer, gyroscope, magneto resistive, Infrared, temperature, and tilt	LabVIEW, TinyOS, MatLab	Bluetooth-enabled wireless device
Enzo *et al.*, [15]	Muscles throughout the body	EMG, strain fabric, electrogoniometer, and piezoelectric	MatLab	DAQ: PC-6036E (NI), wired, smart sensorised shirt for signal monitoring
Worringham *etal*,[20]	Cardiac patients	ECG	GSM-based software	GSM and phone systems
Ahamed *et al.*, [43]	Biceps muscle	EMG	Visual C++	Table PC and Microcontroller
Christopher *et al.*[24]	Stroke patients	Pos and torque	MatLab	Robotic devices
Xing [25] et al.	Stroke patients	EMG	DAQ software	Microcontroller and LCD
Grigore *et al.*, [16]	Uppers	FasTrak	Java, Java 3D games	Rear-projector and quad-core workstation
Mónica *et al.*, [26]	Stroke patients	Torque	Gaming program	PC with graphics accelerator, LCD, and CCD camera
Chee *et al.*, [27]	Stroke patients	Motion	Open GL technique, GUI element	Microcontroller, RF station, can monitor in a PC or PDA
Mohammaddan *et al.*, [5]	Upper limbs	EMG	CAD	Wire driven, flexor cable, DC motor, mild steel cable
Gupta *et al.*, [8]	Cardiac patients	ECG	MatLab	Microcontroller
Mashhour *et al.*, [17] ,	Heart and muscle activities	ECG and EMG	LabVIEW	Microcontroller
Domen et al. [29]	Stroke patients	ECG, force, GSR, sleep-sense flow, and temperature sensor	NM	Haptic device
Nagaoka *et al.*, [40]	Upper limbs	Near-infrared spectroscopy (NIRS)	MatLab	Oxygen monitoring system, & Ethernet online connection.
Takehito *et al.*, [37]	Upper limbs	Force and angle sensor	Application software	Display board and PC
Rotariu *et al.*, [19]	Different places in the body	Intelligent sensor	Wi-Fi or GSM/GPRS connection, database, GUI for ECG wave	Microcontroller board and RF transceivers, wireless sensor, PDA, alarm system, and PC
Hariton *et al.*, [44]	Chronic illness and neurolocomotor	Transducer	Knowledge-based software, informatics management	Wireless network, PC, GSM/GPRS, PDA and multimedia (video, text, images)
Chuanchu *et al.*, [28]	Stroke patients	EEG	GUI, Linux & Windows OS, DAQ software	EEG amplifier, and robot shell
Suresh *et al.*, [30]	Stroke patients	EEG	LabVIEW	NM
Chih-Fu *et al.*, [18]	Upper limbs	EMG	Visual basic, Windows XP, database	PCI counter board, and data acquisition card
Son *et al.*, [46]	Hemiplegia	EMG	EMG measurement software and C program	Biodex, Motor RE 40 (Maxon), and microcontroller
Satoru *et al.*, [38]	Upper limbs	EOG	Image processing software.	Orthosis, video camera
Cartaya *et al.*, [21]	Cardiac patients	ECG	OOP program.	PC, USB port and receiver
Steinisch *et al.*, [31]	Stroke patients	EEG and EMG	Virtual reality software	Robot, haptic device, and online equipments
Sangit *et al.*, [32]	Stroke patients	EMG, pos, and velocity	MatLab, C program	Microcontroller (PIC 24 HJI28) and 16-bit ADC
Zhang *et al.*, [33]	Stroke	Camera and inertial	NM	Notebook, and camera

Mattila *et al.,* [22]	Cardiac patients	ECG	GPRS, 3G mobile network, Java, MySQL	3G mobile, PC, and Blue tooth device
Dobrescu *et al.,* [45]	Chronic patients	Miniature and IrDa	Database (Access, MySQL, PHP), VB/C++	PDA, Laptop, GPRS, 3G, WLAN, and microcontroller
Adel *et al.,* [39]	Upper limb	EMG	VR technology, CCS compiler, C program	Microcontroller, PCB board, and prosthesis
Raichur *et al.,* [34]	Stroke patients	EEG and EMG	LabVIEW 8.0, Windows	Co-processor P4, & NI-USB
Sarela *et al.,* [23]	Cardiac and chronic disease	Mobile sensor (step counter and wellness diary)	MySQL, web service, Sync ML server, Html, XML, AJAX, 3G, GPRS	Mobile technology, Symbian S60 OS, WLAN[c] connectivity, and mobile phone
Stefano *et al.,* [35]	Whole body and stroke patients	Force and torque	CAD, GUI software	Measurement devices for arm, foot, and finger
Pieter *et al.,* [47]	Ankle and spinal cord injury	Pos and orientation	NM	NM
Huijun *et al.,* [41]	Upper limbs	Pos, force, and torque	Visual C++	Camera, and DC servo meter
Nef *et al.,* [42]	Upper limbs	Pos, force, and torque	MatLab/Simulink XPC target, Network system	Haptic device, DC motor, LCD monitors, and amplifiers
Sasidhar *et al.,* [36]	Stroke patients	EMG	MatLab	PC and glove

NM: Not Mentioned, GUI: Graphical user interface. Pos: Position Sensor

Figure 1. *EEG signal recording process [48]*

In these systems, the researchers indicated the various types of hardware and software information that are used as fundamental elements and bridges of communication for the rehabilitation technology. Some of the common software programs used in the rehabilitation systems were MatLab [14, 15, 24, 36], LabVIEW [14], Visual C++[43], Java [23], a GSM-based electrical control system for a cell phone application during rehabilitation [20], virtual reality software [31, 39], image processing software [38], and some open GL techniques. Additionally, some researchers used databases, such as PHP, MySQL, and Microsoft DB. Three studies did not name the software used in the rehabilitation system developed. In contrast, a number of hardware was used during the development of the described rehabilitation systems (Table 1). As shown in Table 1, researchers commonly utilised different types of microcontroller chips, computers, and other devices. Both wireless and wired systems were preferred for signal recording.

Discussions

Assistive technology devices and accurate rehabilitation systems for individuals with motor disabilities caused by the aging process or stroke need a good human-friendly actuator that is compact and environmentally beneficial [49]. The review attempted to answer the following question: "which sensors are used in combination with various software programs, hardware, and other supporting methods to develop an automated rehabilitation system for an impaired human body?" This review attempted to gather the maximum number of software, hardware, sensors, algorithm, prototype, and framework options that are used in rehabilitation systems. Additionally, some restrictions in the rehabilitation mechanism were found. The key finding of this study are the following: 1) a total of 36 articles were reviewed, 2) 54 different types of biosensors have been used in recovery systems, 3) of all of the sensors, EMG and ECG were used more frequently for rehabilitation system development (Table 1), 4) the applicable areas of rehabilitation systems are the brain, heart, ankle, shoulder, finger, biceps, triceps, stroke, cardiac, post stroke, stress, eye, whole body monitor, chronic pain, and older individual (most of the systems were developed for the rehabilitation of the upper limb and stroke and cardiac patients), 5) subjects prefer to feel comfortable with non-invasive electrode placement than needle-based systems, 6) all of the rehabilitation systems provided assistance with a desktop computer or personal digital assistance (PDA), 7) modularity, portability, cost, compactness, and user friendliness are the main concerns of rehabilitation systems, and 8) a number of hardware and software are used to engineer real-time and online systems, e.g., different programming languages, such as C, Visual C++, Java, MatLab, LabVIEW, and web programming tools, microcontroller chips, operating systems, DAQ techniques, application of databases, 3-D models, web technologies, different PDA systems, and client-server database technologies.

The authors of this brief review are confident that recommendations should be based on strong and clear evidence. A powerful level of proof, which is based on reliable findings from a number of high-quality studies, is required, as described in this goal. Thus, based on the evidence, we make the following recommendations, 1) to date, some parts of the body have not been targeted for biosensor-assisted rehabilitation systems because these are out of the sight of the human body, e.g., inner muscles of the human body, muscle tendon area, abdomen, and pre- and post-pregnancy, 2) the advantages in the development of rehabilitation systems have been presented to facilitate future researchers on this endeavour, 3) the existing software and hardware technologies discussed are useful if combined to build a proposed computerised rehabilitation mechanism, and 4) feedback in real time is also important because a physically inactive person (and the therapist) expect clear and live data without delay, and 6) the aim of brief reviews should be to guide rehabilitation researchers toward the most effective and latest techniques. Moreover, this paper suggests that the following issues should be taken into account during the developing of a biosensor-assisted automatic rehabilitation system; first and foremost: online process, non-invasive sensor, affordable cost, various automated signal processing moralisations, not cumbersome, and interactive GUI. Secondary: Portable, i.e., small size, weight and space. There are a number of important limitations to this review. We do not include the robot supported rehabilitations systems or systems without any sensors. Consequently, the present review is unable to explore the availability of the the existing systems on the market (i.e. commercialized rehabilitation systems).

Conclusion

This reviews uncovered 36 papers that matched the defined search criteria: rehabilitation systems with various sensors, software, and hardware. The review also highlights that inexpensive, real-time, non-invasive, effective, easy-to-use, and portable systems are preferred by the end user. The authors of this review hope that this paper provides researchers a good understanding of biosensor-assisted rehabilitation systems and their analysis procedures. This knowledge will assist them in the development of more powerful, flexible, real-time, and well-organised applications related to recovery systems.

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Correspondence to:

Nizam Uddin Ahamed
AI-Rehab Research Group
Universiti Malaysia Perlis (UniMAP)
Kampus Pauh Putra, 02600 Arau, Perlis
Malaysia.