Proprioceptive hand rehabilitation system with progress measurement

Artykuł recenzowany

PRACA ZGŁOSZONA DO KONKURSU

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Słowa kluczowe:
urządzenia do rehabiltacji, rehabilitacja dłoni

Key words:
medical devices for rehabilitation, hand rehabilitation system

Streszczenie

Artykuł bazuje na pracy magisterskiej głównego autora, o takim samym tytule. Celem pracy było zaprojektowanie i wykonanie systemu do rehabilitacji dłoni. Urządzenie jest przeznaczone dla osób z urazami neurologicznymi i ortopedycznymi, powstałymi w wyniku udaru mózgu, chorób układu mięśniowo-kostnego oraz urazów kończyny górnej. System wykorzystuje zdolności neuroplastyczne tkanki nerwowej do tworzenia nowych połączeń i samonaprawy, poprzez stymulację układu proprioceptywnego. Urządzenie zostało wyposażone w czujniki siły, serwomechanizmy cyfrowe oraz sterownik bazujący na mikrokontrolerze. System może pracować autonomicznie. Podłączony do komputera pozwala rejestrować postępy leczenia. Zostały przeprowadzone testy funkcjonalne zaprojektowanego urządzenia. Na ich podstawie i pomysłów autora zaproponowano kierunki jego rozwoju.

Abstract

Article is based on the main author's master's thesis with the same title. The aim of the work was to design and build hand rehabilitation system. Designed device is intended for people with neurological and orthopedic injuries arising from stroke, musculoskeletal diseases and upper limb injuries. The system uses the neuroplastic abilities of nerve tissue to create new connections and healing itself through stimulation of proprioceptive system. The device is equipped with force sensors, digital servomechanisms and control unit based on the microcontroller. The system can work autonomously. Connected to PC allows to register the progress of treatment. Functional tests of designed device were performed. Basing on them and author's ideas development directions were proposed.

Introduction

Nowadays the number of people in need of rehabilitation is increasing. This number, according to the WHO data, is estimated as the 15% of the world's human population. It means over a billion of people is affected by the form of disability. From 110 million for up to 190 million of these people have difficulties in everyday activities [1].

Disability growth rate can related with:

- increasing life expectancy,

- rise in number of people suffering from civilization diseases like stroke, (the second leading cause of death and the third leading cause of disability [2]), rheumatic diseases and the like,
- increasing number of people after injuries caused by car accidents (every year from 20 to even 40 million people lose their moving abilities due to accidents [3]),
- more and more popular extreme sports.

Expect the basic assumption of rehabilitation – preventing the disability, rehabilitation leads to improvement of life quality and health. It is also a tool allowing handicapped people decrease the consequences of accidents and diseases and lead independent, everyday life. In 2014 WHO announced global disability action plan for years 2014-2021 consisting of, inter alia, removing the barriers, improving access to health services and strengthening rehabilitation meaning [4]. Authors of this article decided to sign in the program and design device focused on hand's rehabilitation.

Designing of the system was preceded by overview of proprioceptive hand rehabilitation techniques and devices available on the market. Furthermore, knowledge concerning hand's kinematics was also necessary. Figure 1 shows the simplified kinematics model of a hand, where a) is a Flexion Extension Joint, b) is a Flexion Extension and Abduction Adduction Joint.

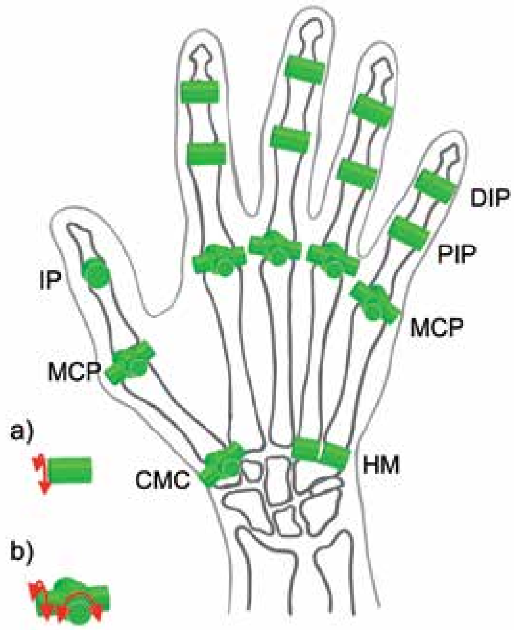

Figure 1. Kinematics of the human hand. Drawn based on [5]

Techniques of proprioceptive rehabilitation

Practicing the proprioception exercises is advisable in neurological diseases or injuries of musculoskeletal system and in preventing traumas. The rehabilitation trainings can be divided (from the patients side of view) on [6]:

- **Single or multi joint active movement.**

During this training patients actively moves a limb, limb segment or the whole body. It consists of upper limb exercises, like reaching to or grasping a target with or without additional sensory feedback (e.g. vision) and directed reaching or grasping with or without assistance. Lower limb tasks are such as stepping on specific targets. This type of rehabilitation can be robot-aided, where movements are guided by online haptic feedback.

- **Single or multi joint passive movement – repetitions of passive limb/joint movement.**

These exercises requires some type of passive motion apparatus and are focused either on single joint (wrist or knee) or multi-joint movement (fingers movement or assisted reaching via robotic arm).

- **Balance training**

Exercises consists of multitude activities including walking and stair stepping exercises, single and double leg balance with and without vision, sit-to-stand exercises, standing, walking, or jumping on stable and unstable surfaces and specific sport exercises, conventional balance training exercises (e.g., balancing on a tilt board), the exercises, including bridging in supine position or maintain sitting or standing balance, were carried out with subject's feet on the vibratory device.

- **Somatosensory stimulation training**

This type of training included different form soft stimulation that was used exclusively to somatosensation like: vibration of whole-body or local, single segment vibration, other forms of stimulation included thermal stimulation, multisomatosensory stimulation, magnetic stimulation , electrical stimulation, and acupuncture.

- **Somatosensory discrimination training**

In this method focused on the ability to discriminate between two somatosensory stimuli. These discrimination training consisted of haptic discrimination (e.g. active exploration of objects with the hand), tactile discrimination (of textures), wrist or ankle joint position, and wrist joint velocity discrimination tasks.

- **Combined/multiple systems training**

Done by using two or more types of training from categories mentioned above.

Overview of hand rehabilitation systems

The classification of hand's rehabilitation systems can be done in different ways. One of them, used mainly in scientific research is mentioned in previous paragraph. Another one, commonly used by the rehabilitation's systems manufacturers is as follow:

- **Passive rehabilitation devices**

During the therapy performed by these devices, patient's role is passive. The therapist or device apply the force to the exercised limb.

- **Active rehabilitation devices**

Movement of the joint is performed solely by patient's muscles.

- **Active assisting rehabilitation devices**

Mobilization of the limb is assisted and controlled by a physiotherapist or a device according to the patient's voluntary movements.

Description of hand rehabilitation device

The goal was to design and build device intended for people with neurological and orthopedic injuries arising from stroke, musculoskeletal diseases and upper limb injuries. Author's intention was to design low weight, low cost, user friendly device, which can lower the physiotherapist involvement in patient's rehabilitation process. As the result passive type, neurological robotic hand rehabilitation device allowing to flex and extend fingers and measure the therapy's progress was built.

In order to facilitate identification of the system, it was called the mark 16. mark 16 allows to move the four fingers attached together and the thumb independly. Movement of mark-16's arms is possible around the thumb's carpometacarpal (CMC) and metacarpophalangeal joint (MCP) simultaneously and around fingers' MCP. In addition, thanks to the additional Degree of Freedom (DoF) over the fingers' proximal interphalangeal joint (PIP) grasping move is improved. Stiffness of this joint can be adjusted. Device's centers of rotation should be positioned over the person index finger's and thumb's MCPs. Depending on the anatomy and the ailment of patient, the tool can be fitted to the patient's hand in a stepless regulation. Thanks to the symmetry of the mark-16, it can be used either on the right or left hand, just by switching the fingers and thumb supports. Specially designed arms (1, 2 in Figure 2), which leaves the palmar area of hand free, allows to catch and to feel by fingers the objects placed in hand is possible.

Safety of the user was crucial. Thus, to fulfill safety requirement, electronically programmable operation angles, speed and torque limits were implemented. Additionally, mark 16 has mechanical limiters of movement, which prevent the overextension of the joints.

Mark-16 is an independent device with embeded controller. Block diagram of the system is shown below in Figure 3. mark-16 is driven by 2 servos with programmable speed, angles and torque limits. Important elements of the system are force sensors, designed for medical purpose (Fig. 3, FS 1, FS 2). Sensors' small dimensions allowed to fit them in the mark-16 arms. Rehabilitation tool is also equipped with LEDs, which in the passive move mode are used for indicating the motion direction, whereas in force measurement, force direction is shown (Fig. 3, LED1, LED2).

mark-16 PC Software

Device, for reading the parameters and measuring the progress of rehabilitation, uses interface im-

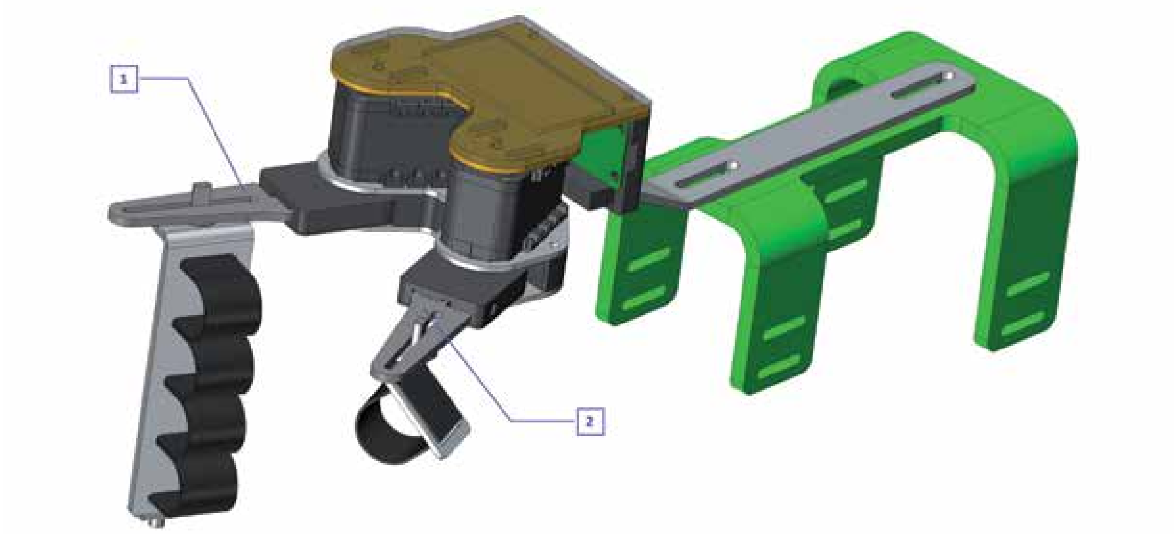

Figure 2. CAD model of the designed system (1, 2 – arms)

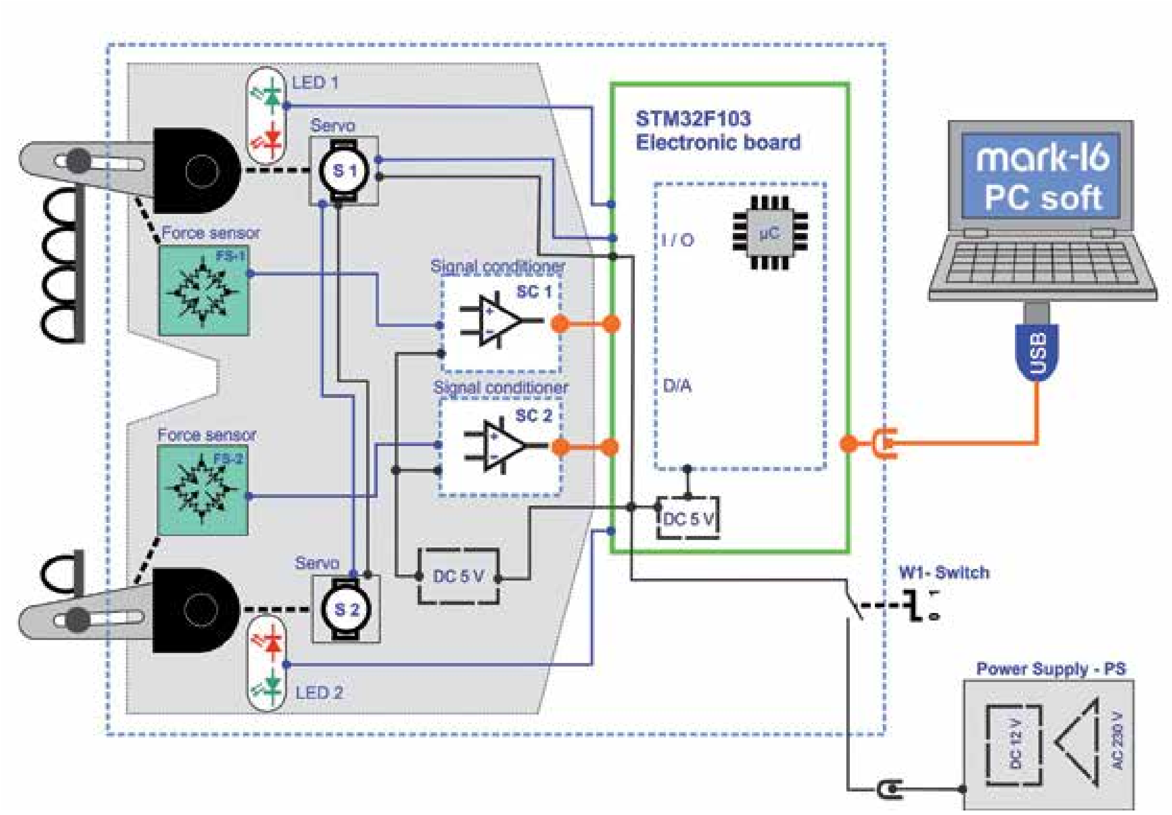

Figure 3. Block diagram of mark-16

plemented on the PC. Its task is to set the current mode, read the possible

Range Of Motion (ROM) angles and data from force sensors. This application allows to chose one of three modes:

1. Force measurement

Currently this state isn't fully implemented. Screen mode has two bar graphs scaled in the percentage of current sensor load used as the force and its direction indicator, while servos are set in the free run mode. Ultimately, the therapist should read force sensor values indicated on the graph bars and values in Newtons. Progress measurement can be done either by comparing this values from different rehabilitation periods, or healthy and disabled hand.

2. Passive movement

It allows for external stimulation stimulation through its fingers movements by the use of servos. These moves influence on the proprioceptive input of the human (stimulates the millions of receptors in skin, joints, ligaments and muscles) and can lead to the activation of the cerebral cortex [7]. Passive moves stimulates the neuroplasticity (possibility of reconstruction the neural connections) and allows to gradually restore the hand functionality.

3. Range measurement

This mode, showed in Fig. 4, allows to capture the ROM between fingers and thumb. Stored values are displayed on the screen. It is possible to save the values on the hard drive. Comparing the history of this data allows to measure the progress of rehabilitation

Functional tests

To check the abilities and ergonomics of mark-16, there were performed tests on the group of 8 healthy people). The aim of the tests was to test the ergonomics of mark 16 as well as checking the possibility of adjusting the device for different hand and forearm sizes.

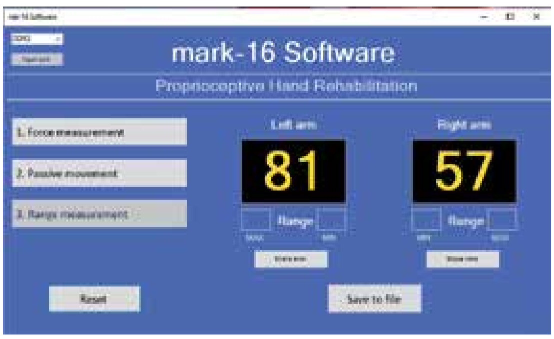

Figure 4. Screenshot of mark-16 software (range measurement mode)

Tests consisted of:

• Ball squeezing (Fig. 5a)

During the next test the force sensors were checked. One after another ball, varying in the size and force needed to squeeze them, were placed in the hand. During the tests the force sensor load was stored.

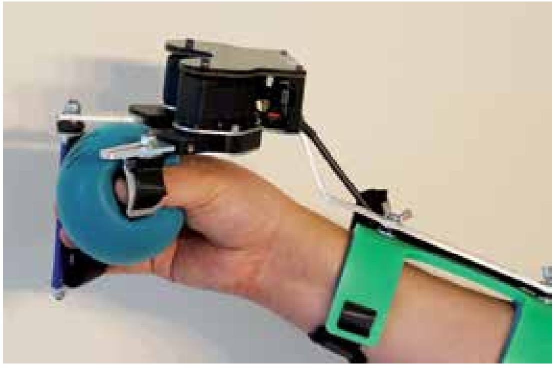

Figure 5a. Ball squeezing

• Passive movements (Fig. 5b)

First functional test of the device based on the passive hand movements. The device performed 3 series of 50 grasping and extension motion. During the test the ergonomics and mark-16 behavior were checked.

Figure 5b. Mark-16 in motion – extended hand.

• Objects grasping

The possibility of grasping different shapes was checked. Test was performed on the cylinder. Construction of mark-16 caused the tilting of cylinder. To ensure the correct grip, the shape of the device's arms should be changed.

Possibilities of development

To improve the functionality of the device, authors defined the directions of developing it. mark-16 allows to move the thumb and all four fingers together. It isn't the natural hand's behavior. Improved system should have fingers separated, to let them flex and extends individually. Adding a possibility of performing the active rehabilitation, by implementing the force controller, will significantly increase the rehabilitation abilities. Replacing the power supply by a batteries and creating the onboard user interface will make the mark-16 portable system. Study of a hand anatomy and its kinematics should help creating the more ergonomic, imitating the natural moves, bionic hand rehabilitation system. mark-16 can be fitted with EMG signals electrodes. Attaching the electrodes over the muscles of forearm, should allow reading the patient's intentions and help them in rehabilitation training or even grasp objects in everyday life. Creating the game, which uses the external monitor, and its integration with the mark-16 as joystick – controller, should improve the effectiveness of the rehabilitation process. Final version of device should be portable.

Summary

The project objective was to design and make the assisting hand rehabilitation system. During the tests, the influence of the rehabilitation on the improvement of proprioceptive feeling couldn't been checked. Pilot studies on the group of people, showed imperfection of the ergonomics. To cope with different sizes of hands and forearms the extended regulation of a forearm's circumstances should be provided. Additional regulation of distance between the MCP's joint would allow to use the mark-16 on children's hands. Choosing the composites or other modern materials could reduce the current weight of device (550 grams). mark 16 requires tests, research and evaluation done by specialists in physiotherapy, concerning the usage of device in real-life conditions. Presented solution is just the beginning of a way. However authors hopes, that the experience gained during the project will allow to design modern and ergonomic system helping people with diseases, birth defects and injuries.

References

[1] WHO fact sheet [online]. Available: www.who.int/mediacentre/factsheets/fs352/en/

[2] WHO data. [online]. Available: www.who.int/healthinfo/global_burden_disease/en/

[3] WHO road traffic injuries - fact sheet. [online]. Available: www.who.int/mediacentre/factsheets/fs358/en/

[4] WHO global disability action plan 2014-2021. [online]. Available: www.who.int/disabilities/actionplan/en/

[5] Chen, I.M., Li, K., Lim, C.K. & Yeo, S.H., 2011. Development of finger-motion capturing device based on optical linear encoder, Journal of Rehabilitation Research & Development 48, pp. 69-82.

[6] I-Ling Yeh Joshua E. Aman, Naveen Elangovan and Jürgen Konczak. The effectiveness of proprioceptive training for improving motor function: a systematic review. [online]. Available: www.ncbi.nlm.nih.gov/pmc/articles/PMC4309156/

[7] M.S. Kaplan. Plasticity after brain lesions: contemporary concepts. Archives of Physical Medicine and Rehabilitation, 1988.