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Robotic Fingers in Reach-to-Grasp Tasks of Rehabilitation

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Abstract

The REHAROB robotic upper limb rehabilitation system was improved with a custom-designed and developed hand/finger therapy module. The new module extends the scope of the applicable motion therapy from passive to active reach-to-grasp activities of daily living tasks, and the range of treated anatomical joints was also extended to every proximal and distal upper limb anatomical joint. Finger exercising and object grasping are supported with a pair of two degree-of-freedom (DOF) robotic fingers. One of the robotic fingers moves the index/middle/ring fingers together, whereas the other robotic finger moves the thumb. A novel hypothesis was established, analyzed, and tested for setting the orientation of the robotic finger moving the thumb. The robotic thumb is not aligned with the patient's thumb; its orientation is optimized in the patient's hand reference system to maximize the efficiency in the opposite grasping task. While most concurrent systems utilize virtual objects for grasping tasks, the REHAROB system exercises five carefully selected reach-and-grasp type activities of daily living (ADL) with real objects. Actuating the human finger phalanges through custom development finger orthoses is described. An advanced feature of the hand/finger therapy module is the left-right hand side changeover by only alternating the orientation of the robotic fingers and exchanging the finger orthoses.

Keywords

rehabilitation robot, post-stroke rehabilitation, hand/finger therapy module

1 Introduction

Several upper limb and lower limb rehabilitation robots have already been transferred from research to practice, establishing a wealthy market in rehabilitation robotics [1–4]. Besides the existing ecosystem issues in poststroke rehabilitation, relevant scientific and technological challenges require further attention [5], such as expanding the robotic assistance from the chronic phase towards the acute phase of stroke, from institutions towards home, from isolated body parts towards the whole body, and from repetitive towards cognitive training style. The objectives of the current research were set according to some of these challenges. Accordingly, the REHAROB therapeutic platform was upgraded with a hand therapy module into a whole upper limb rehabilitation robot that simultaneously exercises the proximal and distal anatomical joints in tasks of activities of daily living (ADL) where reach-to-grasp and manipulation of real objects takes place.

2 Materials and methods

2.1 Therapeutic goals in robot-assisted hand and finger motion therapy

It is a widely accepted fact in poststroke rehabilitation that after the acute phase, the recovery of hand function is one of the most challenging parts of motor rehabilitation [6]. In neurological rehabilitation, there are several legitimate types of robot-assisted training for the passive, the active assisted, and the active resisted phases of motion therapy [7]. While it was observed that robotic tools of neurorehabilitation are effective in reducing motor

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impairment [8], their performance in improving function is still limited. The complexity of the hand function leads to major difficulties in the development of devices that allow the training of the whole upper limb including the hand. In hand training, most of the existing rehabilitation robots are designed to train the pressure of the hand without finger extension. The current systems that provide finger flexion and extension during training are stationary and/or wearable hand therapy systems, which limit the range of therapy only to the fingers [9]. Consequently, enhancing the capabilities of upper limb rehabilitation robots with hand training function results major benefit to the patients.

2.2 Design requirements for the REHAROB hand therapy module

To survey the design requirements of prominent laboratory and commercial hand therapy devices, the relevant existing systems were studied like the Rutgers Master II [10], and the HWARD hand-wrist assisting robotic device [4], the Finger exoskeleton [11], the Hand Mentor [12], the Hand of hope [13], the Amadeo [7, 14, 15] and the Reha-Digit [16] stationary hand therapy devices, together with the InMotion Wrist Robot [17] and the ArmeoTherapy [18] robot mounted hand therapy devices. Based on these studies and the available resources, the design requirements for the improved REHAROB 2.0 Hand Therapy Module were defined as follows:

- Support cylindrical and spherical power grasp of objects in five selected ADL tasks identified as:
  1. mug handle,
  2. phone handset,
  3. zipper puller,
  4. door handle,
  5. tissue/sponge.
- Provide active support to opposite closing and opening of the thumb.
- Provide active support to flexion and extension of the index-middle-ring fingers.
- Adapt to the physical deformity of the spastic hemiparetic hand.
- Ensure side independent ergonomic comfort of the male-female side in the 5 percentile – 95 percentile anthropometric range.
- Leave the inner skin tactile receptors free at the phalanges and the palm.
- Place body interfaces at the hand back splint, at the index-middle-ring intermediate phalange splints, and at the thumb distal phalange splint.
- Provide pull-push forces of max 100 N at each robotic finger.
- Close and open the hand in 1 s or slower.

2.3 Concept of hand and finger exercising

The first version of the REHAROB Therapeutic System (REHAROB 1.0) performed a full range of continuous passive motion therapy of spastic hemiparetic patients with combined 5 degree-of-freedom (DOF) shoulder, and 2 DOF elbow exercises in a dual robotic arm set-up [19]. The coordinated shoulder and elbow exercises helped increase the range of motion (ROM), maintain proprioception, and reduce spasticity [20]. However, the system at that time was incapable of exercising the wrist and the fingers.

REHAROB 2.0 opened the way to exercise synchronously all anatomical joints of the upper limb by relocating the body interfaces towards the distal regions of the exercised upper limb. In the new REHAROB 2.0 system, the IRB 1600 robotic arm pronates-supinates, radial-ulnar deviates, and flexes-extends the wrist through the hand interface, while the IRB 140 robotic arm moves all the anatomical joints of the shoulder and the elbow through a lower arm interface (see Fig. 1).

The new REHAROB 2.0 Hand Therapy Module (see Fig. 2) applies two identical 2 DOF robotic fingers of the SDH-2 3-finger robot hand of SCHUNK GmbH & Co KG.

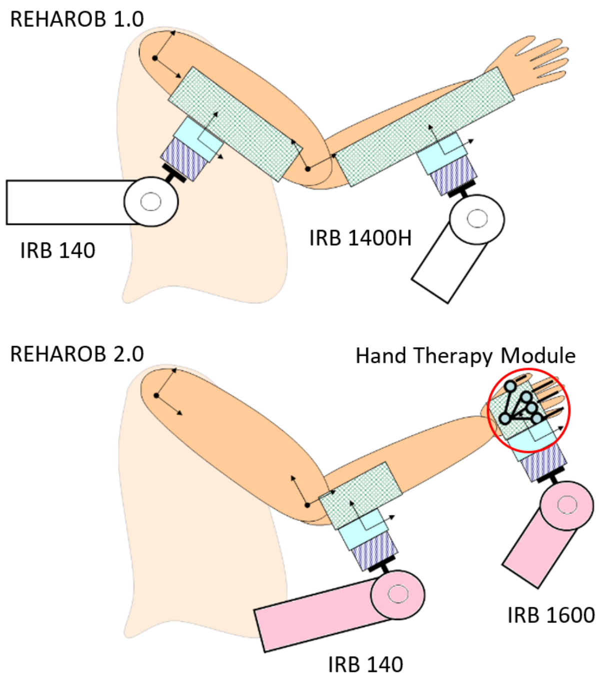


Fig. 1 Complementing shoulder and elbow movements with wrist and finger movements in REHAROB 2.0

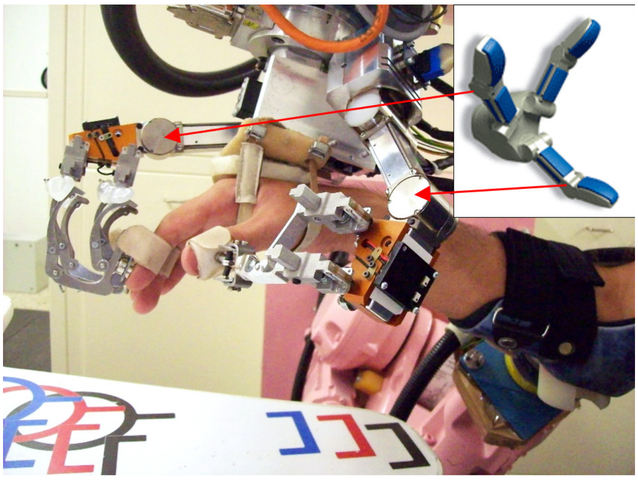


Fig. 2 The REHAROB 2.0 Hand Therapy Module.
Small picture: SDH-2 3 finger robot hand.

The tactile pads of the SDH-2 robotic fingers have been removed. One of the 2 DOF robotic fingers moves the thumb. In contrast, the other 2 DOF robotic finger moves the index finger, the middle finger, and the ring finger together, employing a custom-made compliance mechanism.

2.4 Spatial arrangement of the robotic fingers in the hand therapy module

One of the main challenges was to locate the two robotic fingers in the Hand Therapy Module. Adduction and abduction of the metacarpophalangeal (MCP) joints of the index-middle-ring fingers are not supported in our concept. To allow kinematic alignment for all MCP, proximal interphalangeal (PIP), and distal interphalangeal (DIP) flexion-extension axes in the index-middle-ring fingers, the reference plane of the corresponding 2 DOF robotic index-middle-ring finger had to be orthogonal to the parallel MCP, PIP, and DIP flexion-extension axes of the middle finger. Consequently, the robotic finger had to be positioned and oriented within this plane, and it also had to allow at least 0–45 degree MCP flexion and at least 0–90 degree PIP flexion of the middle finger (see Fig. 3). Based on these requirements, a genetic algorithm was applied to find an optimal robotic index-middle-ring finger arrangement [21].

The thumb is required to perform an opposition movement in all the five selected ADL tasks. The ideal plane of the 2 DOF robotic thumb was determined experimentally. The carpometacarpal (CMC) joint of the thumb is a 2 DOF saddle joint that allows the thumb to oppose the other fingers. Flexions in the MCP and the interphalangeal (IP) joints complete the opposition movement of the thumb. During grasping, the thumb performs a 4 DOF spatial movement, whereas the index-middle-ring-little fingers perform a 3 DOF planar movement. During the thumb opposition experiments, we observed that a point on the thumb moves along a planar path. A two-camera optical measurement set-up was built for this analysis. Both cameras were placed at equal distances from the hand, orthogonal to each other. A marker was fixed to the thumb and tracked by the two cameras. The marker was then slightly displaced, and the experiment was repeated several times. The 2D coordinates of the marker on each camera frame were determined in arbitrarily chosen coordinate systems. Finally, the 2D coordinates of the markers were imported into a 3D CAD environment where the spatial marker paths were reproduced (see Fig. 4 (a)). To illustrate the two classes of points moving in 2D or in 3D, the red marker traces a 2D path, whereas the white marker traces a 3D path trajectory. The 2 DOF robotic thumb must be connected to the human thumb through red marker that allows the planar thumb opposition. The result was experimentally verified by grasping the mug's handle with the pre-prototype of the REHAROB 2.0 Hand Therapy Module (see Fig. 4 (b)).

The 2 DOF robotic thumb must be placed in the reference plane of the red marker. Translating this result into engineering transformation, the plane of the middle finger

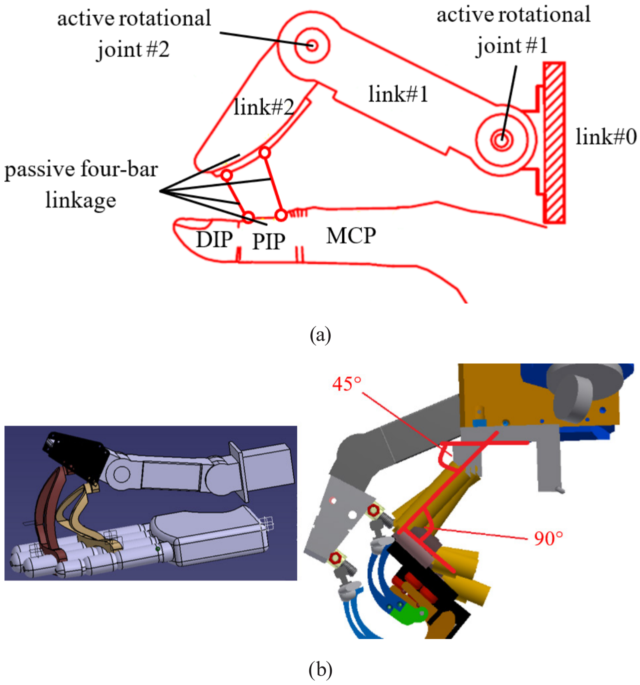


Fig. 3 (a) Kinematic chain of the robotic index-middle-ring finger actuation with active and passive DOFs. (b) Range of motion of the actuated human finger joints: MCP flexion: 0–45 degree, PIP flexion: 0–90 degree

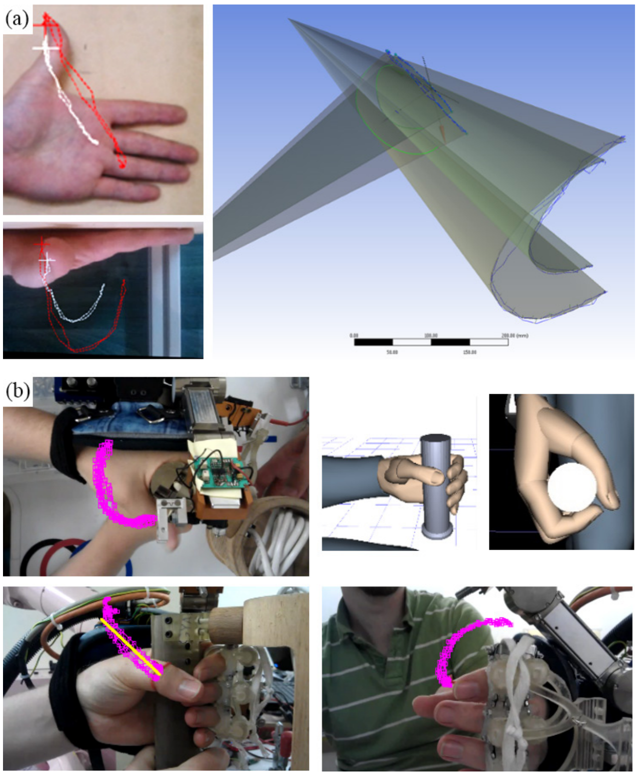


Fig. 4 Tracking of various markers on the thumb. (a) red marker moves on 2D path, white marker moves 3D path, (b) verification of the 2D path by the mug's handle grasping

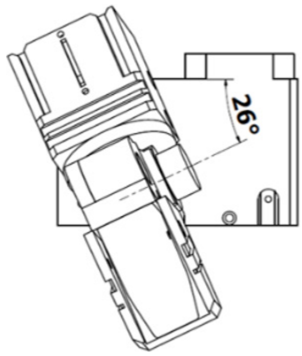
robotic finger needs to be rotated by 5 degrees around a vertical axis, and then by 26 degrees around a horizontal axis (presented in the top view and the front view of Fig. 5, respectively). This is the way how the reference plane of the 2D robotic thumb is obtained.

Finally, the exact position of the robotic thumb within this plane (c.f. Fig. 2) was determined by the size of the thumb orthosis as well as the joint limits of the robotic finger.

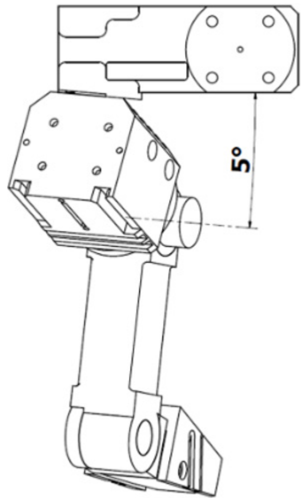
2.5 Development of the finger orthoses

The index-middle-ring fingers are connected to the 2D robotic index-middle-ring finger by a four-bar linkage mechanism that is ergonomically shaped, hand size adjustable, and distributes the grasping force appropriately. This mechanism transfers the motion from the robotic finger to the intermediate phalanges of the human fingers using detachable, tailor-made thermoplastic splints. The REHAROB 2.0 Hand Therapy Module makes the fingertips of the index-middle-ring-little fingers uncovered so the participant can use his/her tactile sensation during grasping of the ADL objects (see Fig. 6).

Unlike the orthoses of the index-middle-ring fingers, the thumb orthosis is connected to the distal phalange to get full control over the thumb opposition. In the first version of the orthosis, a unisize "C" shaped thermoplastic



(a)



(b)

Fig. 5 Proper orientation of the 2D robotic thumb ((a) front view; (b) top view)

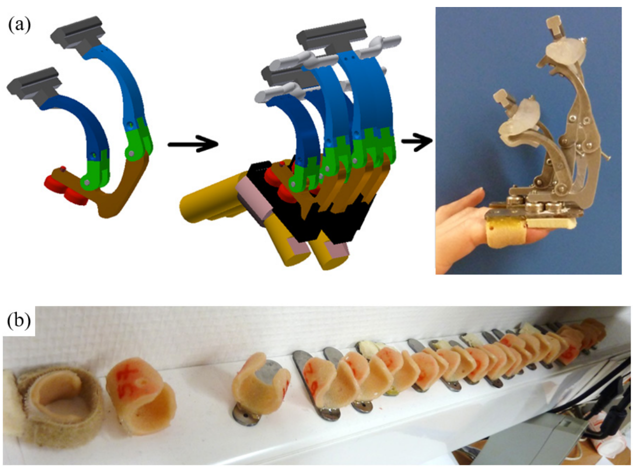


Fig. 6 (a) CAD models and photo of the index-middle-ring finger orthosis. (b) Detachable thumb splint (far left) and detachable tailor-made index-middle-ring intermediate phalange splints

splint is surrounded with Velcro tape for excellent fixation (see Fig. 7 (a)). A thin silicon layer on the inner side of the splint helps embracing the thumbnail. The "C" shaped splint element is connected to the triangular frame through a ball joint. After initial usability tests, the ball joint was

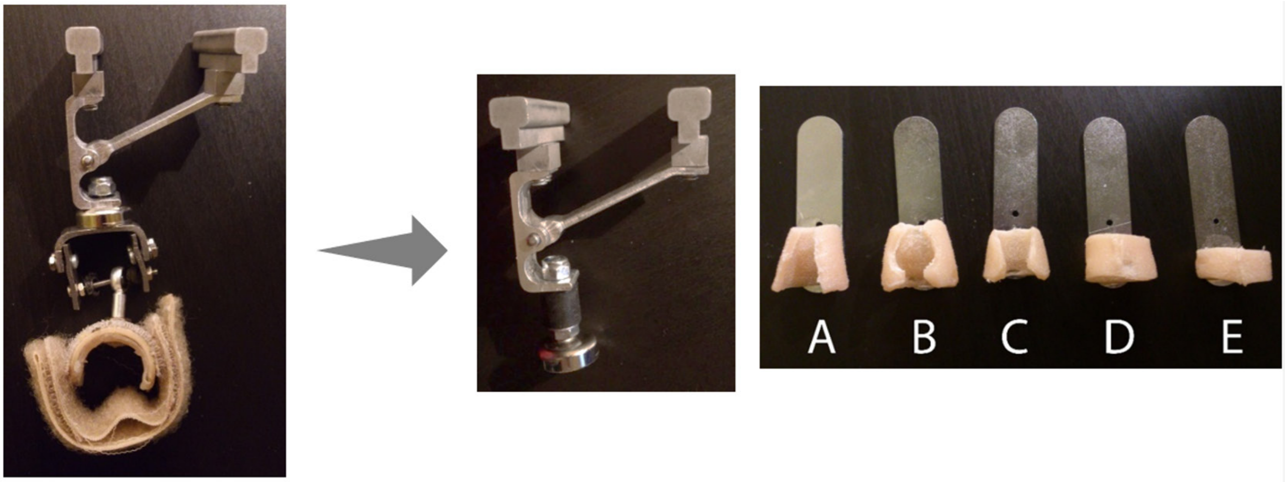


Fig. 7 (a) Initial and (b) final versions of the thumb orthosis with design options of the thumb distal phalange splint

replaced with a silicon rubber spring (see Fig. 7 (b)) which can transmit compressing force better than the ball joint. The unisize splint was replaced with size series splints that are detachable using a neodymium magnet just as the index-middle-ring finger orthoses. Five different shapes were designed and prototyped (see Fig. 7 (b)). Version B was assessed the best, which was then produced in a sufficient number of different sizes.

2.6 Changeover of the treatment side

A major challenge in the design of a hand therapy device is the solution to the Left/Right-Right/Left changeover. The REHAROB 2.0 Hand Therapy Module minimizes the changeover tasks by alternating only the orientation of the robotic fingers according to being in the middle finger or thumb configuration.

The REHAROB 2.0 Hand Therapy Module can be transformed from Left/Right to Right/Left side in 8 steps. It is the 3rd step, for example, when the robotic finger is temporarily taken off the Hand Therapy Module (see Fig. 8). The step that includes the handling of the ribbon cable was proven to be the most complicated task of the changeover process.

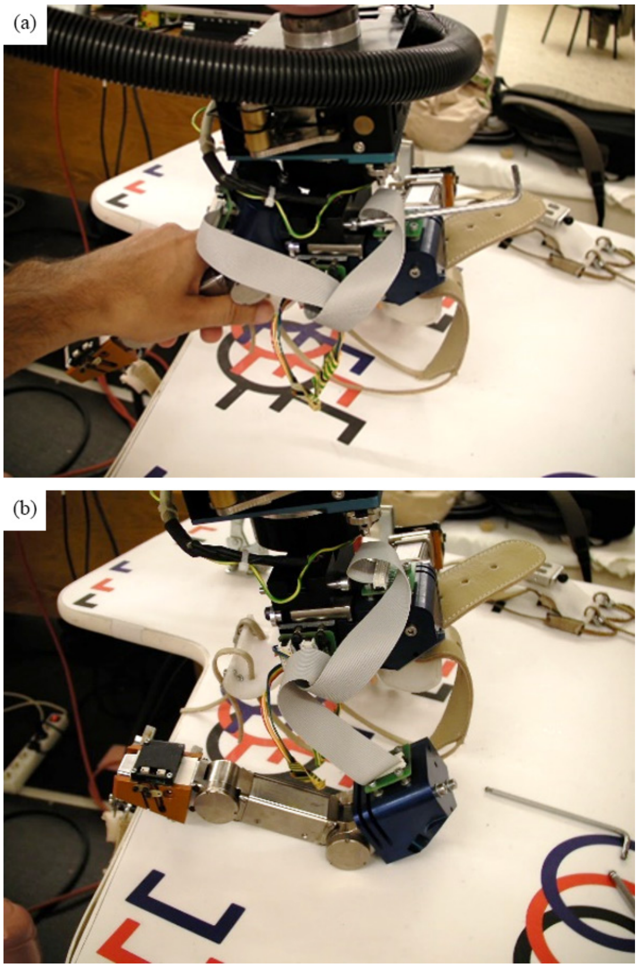


Fig. 8 (a) The therapist grasps the robotic thumb set to the right hand. (b) The robotic thumb is placed on the desk before its transformation into a left-hand robotic index-middle-ring finger

2.7 Movement therapy by real-world activities of daily living

Since the beginning of robotic rehabilitation, robot-mediated neurorehabilitation has endeavored to overcome simple gymnastic (c.f. Continuous Passive Motion) exercises by rendering real-time interaction between the robot-assisted participant and the virtual world. The virtual reality scenarios can be grouped into artificial (game-like) and natural exercises. The second group includes the simulation of the Activities of Daily Living (ADLs) [22], which are essential means of functional movement rehabilitation. Exercising ADLs requires complex 3D motions, coordination of anatomic joints, constrained and free motions, near and far motions, and grasping and manipulating objects. Interaction with real objects improves the effectiveness of rehabilitation with stimuli like surface properties, temperature, or inertial properties. Accordingly, five ADL tasks have been selected based on the following requirements:

1. compliance with the Bobath and the Proprioceptive Neuromuscular Facilitation rules;
2. inclusion of proximal and distal anatomical joint motions;
3. significant range of motion in all upper extremity anatomical joints;
4. object grasping performed by opposition movement of the thumb and flexion of the fingers (closing movement) (see Fig. 9).

The five ADL tasks have been standardized, scaled for Small (black vignette), Medium (red vignette), and Large (blue vignette) anthropometric sizes. To get the starting positions of the Small-Medium-Large vignettes on the desktop for each ADL object, the 5 percentile female and the 95 percentile male mannequins were simulated in the Siemens Tecnomatix Jack® ergonomics simulator toolkit. The anatomic joint angles were standardized for every ADL exercise. Customized genderfree mannequins were created for the 27.5 percentile (S_{mean} height: 158.4 cm), 50 percentile (M_{mean} height: 169.7 cm), and 72.5 percentile (L_{mean} height: 181.0 cm) anthropometric sizes. The person is classified Small if his/her height is between 152.8 cm and 164.1 cm, Medium between 164.1 cm and 175.4 cm, and Large between 175.4 cm and 186.7 cm. The reach-to-grasp ADL tasks do not require the patient to make a fist, but to grasp a cylinder or sphere of diameter of 30 mm. The range of motion for the human middle finger was simulated in the Siemens Tecnomatix Jack® ergonomics simulator toolkit (see Fig. 10 and Table 1) and remain within the range of motion thresholds of the robotic index-middle-ring finger (see Fig. 3 (b)).

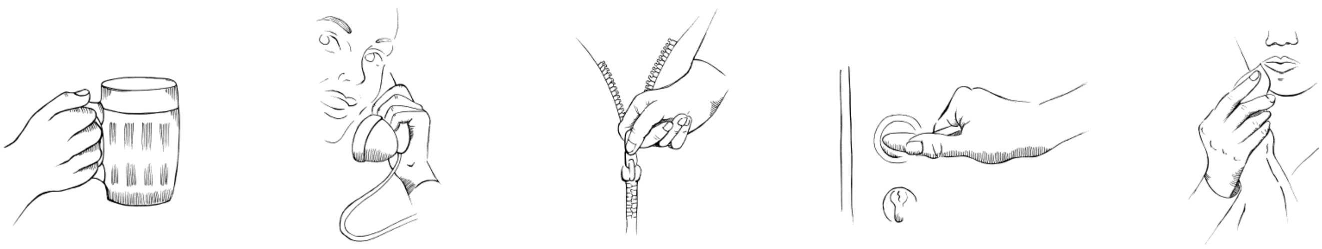
3 Results and discussion

3.1 Ergonomic tests

For teaching the reference trajectories of the REHAROB 2.0 Hand Therapy Module in assistive therapy mode, zero impedance and admittance control schemes [23] were developed and several tests were carried out to check the achievable functionalities of the system. As an example, an L-size healthy test person demonstrates how the REHAROB Therapeutic System assists a patient in zero impedance control mode during an ADL exercise (see Fig. 10 and Table 1).

3.2 Clinical trial

A clinical trial involving 20 chronic poststroke participants was carried out on the REHAROB 2.0 Therapeutic System with the integrated Hand Therapy Module. All the participants were post stroke over one year and they all received 20 sessions. Each therapy session consisted of a passive motion therapy session and an active task therapy session. The latter included one-time passive and five times active-assisted exercising of all the five ADL tasks defined in the design requirements above. Fugl-Meyer upper extremity subsection, Modified Ashworth Scale, Action Research Arm Test, Functional Independence Measure, and Barthel Index were assessed one month prior, at the start, in the end, and three months after the therapy course. While no significant change was found in the Modified Ashworth Scale and Barthel Index, all the three other scales showed significant improvements from the start until the end of the therapy. For more details, such as the clearance of an Ethical Board, the cohort, the percentage of left/right impairment, age distribution, percentage of male/female, and improvement of scales, see [24].



(a) (b) (c) (d) (e)

Fig. 9 ADL tasks selected for active robot-mediated reach and grasp therapy with REHAROB 2.0. Free motions: (a) drinking; (b) telephoning. Path-constrained motions: (c) zipping and unzipping a vest; (d) opening a door. Force constrained motion: (e) cleaning the mouth with tissue/sponge.

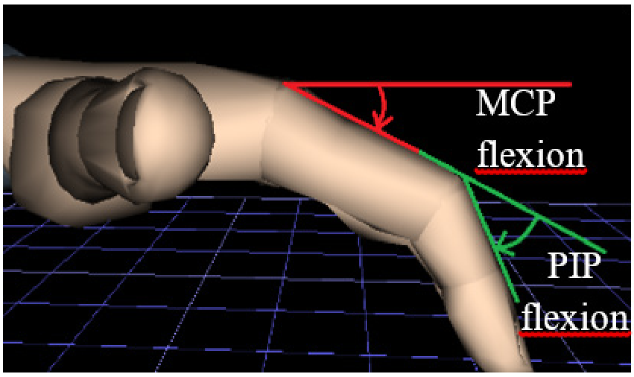


Fig. 10 Flexion angles of the Metacarpophalangeal (MCP) and the Proximal Interphalangeal (PIP) finger joints

Table 1 Anatomic angles of the actuated middle finger joints when grasping five ADL objects with a cylindrical or spherical reference diameter of 30 mm

ADL object	MCP flexion [deg]	PIP flexion [deg]
Mug handle	30.8	83.4
Telephone handset	21.4	71.7
Zipper puller	43.7	81.1
Door handle	40.2	88.0
Sponge	29.8	63.6

4 Conclusions

The design requirements, the major challenges, and the applied methodology of the design process were summarized in the case of the development of a robotic finger-based Hand Therapy Module. The module was constructed as a part of the REHAROB 2.0 Therapeutic System. A pair of identical commercial 2 DOF robotic fingers serves as the basic actuators of the module, which extends the motion therapy range of the REHAROB 2.0 system to all proximal and distal anatomical joints of the upper limb.

The robotic index-middle-ring finger is aligned with the human middle finger as a state-of-the-art exoskeleton. The novelty of the Hand Therapy Module lies in the 3D geometrical arrangement of the robotic thumb. To get the robotic thumb's orientation, the robotic index-middle-ring finger must be rotated by 5 degrees, then by 26 degrees around two base axes of the hand reference frame. For active-assisted therapy five reach-to-grasp type Activity of Daily Living tasks were selected. The novelty of the REHAROB 2.0 approach is the robot assisted reach-to-grasp interaction with real objects. To overcome the technical limitations of the REHAROB 2.0 Hand Therapy Module such as the challenging left-right hand side change-over, the ribbon cables (see Fig. 8) and the bulky four-bar linkage (see Fig. 11), the REHAROB 3.0 Hand Therapy Module is under development [25]. The REHAROB 3.0 Therapeutic System under development includes not only a new hand therapy module, but the IRB140 and IRB1600 standard industrial robots have been replaced by the UR5e and UR10e collaborative robots.

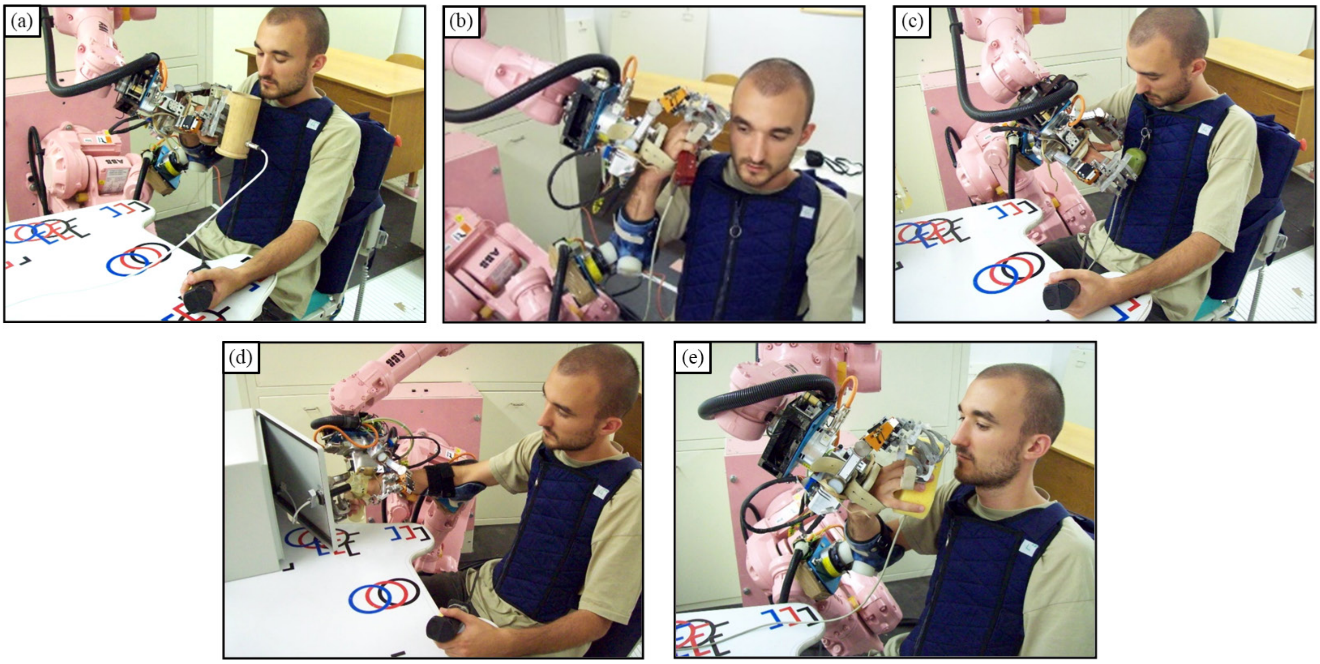


Fig. 11 Performing the five ADLs with REHAROB 2.0: (a) drinking from a mug; (b) picking up a phone; (c) zipping and unzipping a vest; (d) opening a door; (e) cleaning the mouth with a sponge.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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References

[1] Brackenridge, J., Bradnam, L. V., Lennon, S., Costi, J. J., Hobbs, D. A. "A Review of Rehabilitation Devices to Promote Upper Limb Function Following Stroke", Neuroscience and Biomedical Engineering, 4(1), pp. 25–42, 2016.
https://doi.org/10.2174/2213385204666160303220102

[2] Fazekas, G., Tavaszi, I. "The future role of robots in neuro-rehabilitation", Expert Review of Neurotherapeutics, 19(6), pp. 471–473, 2019.
https://doi.org/10.1080/14737175.2019.1617700

[3] Louie, D. R., Eng, J. J. "Powered robotic exoskeletons in post-stroke rehabilitation of gait: a scoping review", Journal of NeuroEngineering and Rehabilitation, 13, 53, 2016.
https://doi.org/10.1186/s12984-016-0162-5

[4] Mehrholz, J., Pohl, M., Platz, T., Kugler, J., Elsner, B. "Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke", [preprint] Cochrane Database of Systematic Reviews, 9, CD006876, 03 September 2018.
https://doi.org/10.1002/14651858.CD006876.pub5

[5] Fazekas, G. "Robotics in rehabilitation: successes and expectations", International Journal of Rehabilitation Research, 36(2), pp. 95–96, 2013.
https://doi.org/10.1097/MRR.0b013e32836195d1

[6] Volpe, B. T., Lynch, D., Rykman-Berland, A., Ferraro, M., Galgano, M., Hogan, N., Krebs, H. I. "Intensive Sensorimotor Arm Training Mediated by Therapist or Robot Improves Hemiparesis in Patients With Chronic Stroke", Neurorehabilitation and Neural Repair, 22(3), pp. 305–310, 2008.
https://doi.org/10.1177/1545968307311102

[7] Orihuela-Espina, F., Roldan, G. F., Sanchez-Villavicencio, I., Palafox, L., Leder, R., Sucar, L. E., Hernández-Franco, J. "Robot training for hand motor recovery in subacute stroke patients: A randomized controlled trial", Journal of Hand Therapy, 29(1), pp. 51–57, 2016.
https://doi.org/10.1016/j.jht.2015.11.006

[8] Johnson, M. J. "Recent trends in robot-assisted therapy environments to improve real-life functional performance after stroke", Journal of NeuroEngineering and Rehabilitation, 3, 29, 2006.
https://doi.org/10.1186/1743-0003-3-29

[9] Georgiou, T. A., Asnaghi, D., Liang, A., Agogino, A. M. "The Sparthan Three-Dimensional Printed Exo-Glove: A Preliminary Evaluation of Performance Via Case Study", Journal of Medical Devices, 13(3), 031007, 2019.
https://doi.org/10.1115/1.4043976

[10] Bouzit, M., Burdea, G., Popescu, G., Boian, R. "The Rutgers Master II-new design force-feedback glove", IEEE/ASME Transactions on Mechatronics, 7(2), pp. 256–263, 2002.
https://doi.org/10.1109/TMECH.2002.1011262

[11] Wege, A., Kondak, K., Hommel, G. "Mechanical design and motion control of a hand exoskeleton for rehabilitation", IEEE International Conference Mechatronics and Automation, 2005, 1, pp. 155–159, 2005.
https://doi.org/10.1109/ICMA.2005.1626539

[12] Housley, S. N., Garlow, A. R., Ducote, K., Howard, A., Thomas, T., Wu, D., Richards, K., Butler, A. J. "Increasing Access to Cost Effective Home-Based Rehabilitation for Rural Veteran Stroke Survivors", Austin Journal of Cerebrovascular Disease & Stroke, 3(2), pp. 1–11, 2016.

[13] Calderon, C. A., Ramirez, C., Barros, V., Punin, G. "Design and Deployment of Grasp Control System applied to robotic hand prosthesis", IEEE Latin America Transactions, 15(2), pp. 181–188, 2017.
https://doi.org/10.1109/TLA.2017.7854610

[14] Helbok, R., Schoenherr, G., Spiegel, M., Sojer, M., Brenneis, C. "Robot-assisted hand training (Amadeo) compared with conventional physiotherapy techniques in chronic ischemic stroke patients: a pilot study", presented at 21st Annual Conference Bremen: German Society for Neurorehabilitation (DGNR), Bremen, Germany, Nov., 4-6, 2010.

[15] Jakob, I., Kollreider, A., Germanotta, M., Benetti, F., Cruciani, A., Padua, L., Aprile, I. "Robotic and Sensor Technology for Upper Limb Rehabilitation", PM&R, 10(9S2), pp. S189–S197, 2018.
https://doi.org/10.1016/j.pmrj.2018.07.011

[16] Hesse, S., Kuhlmann, H., Wilk, J., Tomelleri, C., Kirker, S. G. "A new electromechanical trainer for sensorimotor rehabilitation of paralysed fingers: A case series in chronic and acute stroke patients", Journal of NeuroEngineering and Rehabilitation, 5, 21, 2008.
https://doi.org/10.1186/1743-0003-5-21

[17] Mazzoleni, S., Dario, P., Posteraro, F., Iardella, L. "Effects of combined transcranial direct current stimulation and wrist robot-assisted therapy in subacute stroke patients: preliminary results", In: 2015 IEEE International Conference on Rehabilitation Robotics (ICORR), Singapore, Singapore, 2015, pp. 217–222. ISBN 978-1-4799-1807-2
https://doi.org/10.1109/ICORR.2015.7281202

[18] El-Shamy, S. M. "Efficacy of Armeo® robotic therapy versus conventional therapy on upper limb function in children with hemiplegic cerebral palsy", American Journal of Physical Medicine & Rehabilitation, 97(3), pp. 164–169, 2018.
https://doi.org/10.1097/PHM.0000000000000852

[19] Fazekas, G., Horvath, M., Toth, A. "A novel robot training system designed to supplement upper limb physiotherapy of patients with spastic hemiparesis", International Journal of Rehabilitation Research, 29(3), pp. 251–254, 2006.
https://doi.org/10.1097/01.mrr.0000230050.16604.d9

[20] Arz, G., Toth, A., Fazekas, G., Bratanov, D., Zlatov, N. "Three-dimensional anti-spastic physiotherapy with the industrial robots of "REHAROB"", presented at Proceedings of the Eighth International Conference on Rehabilitation Robotics, Daejon, Republic of Korea, Apr., 23-25, 2003.

[21] Horváth, T. "Rehabilitációs célú mechanizmus tervezése emberi- és robotujjak kinematikai kapcsolásához" (Kinematic coupling of SCHUNK and human fingers), In: Tudományos Diákköri Konferencia (Annual Scientific Student Association's Conference), Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Budapest, Hungary, 2011, p. 15. (in Hungarian)

[22] Lawton, M. P., Brody, E. M. "Assessment of older people: self-maintaining and instrumental activities of daily living", The Gerontologist, 9(3_Part_1), pp. 179–186, 1969.
https://doi.org/10.1093/geront/9.3_Part_1.179

[23] Miao, Q., Zhang, M., Cao, J., Xie, S. Q. "Reviewing high-level control techniques on robot-assisted upper-limb rehabilitation", Advanced Robotics, 32(24), pp. 1253–1268, 2018.
https://doi.org/10.1080/01691864.2018.1546617

[24] Peter, O., Tavaszi, I., Toth, A., Fazekas, G. "Exercising daily living activities in robot-mediated therapy", Journal of Physical Therapy Science, 29(5), pp. 854–858, 2017.
https://doi.org/10.1589/jpts.29.854

[25] Bauer, M. O., Vizi, M. B., Galambos, P., Szalay, T. "Direct Drive Hand Exoskeleton for Robot-assisted Post Stroke Rehabilitation", Acta Polytechnica Hungarica, 18(5), pp. 37–54, 2021.
https://doi.org/10.12700/APH.18.5.2021.5.4