“Handreha”: A new Hand and Wrist Haptic Device for Hemiplegic Children

Mohamed Bouri, Charles Baur, Reymond Clavel

Ecole Polytechnique Fédérale de Lausanne
Laboratoire de Systèmes Robotiques (LSRO)
CH 1015, Switzerland
Mohamed.Bouri@epfl.ch, Charles.baur@epfl.ch ,
Reymond.clavel@epfl.ch

Milan Zedka, Christopher John Newman

Nestlé Hospital CHUV
Service of Neurology and Pediatric Neurorehabilitation
CH 1011 Lausanne, Switzerland
Christopher.Newman@chuv.ch, Milan.zedka@chuv.ch

***Abstract*— This paper presents the development of a new haptic device for hand rehabilitation for hemiplegic children. “Hanreha” has been developed at the EPFL thanks to the interest of the “Neurology and Pediatric NeuroRehabilitation” Service of the CHUV (Centre Hospitalier Universitaire du Canton de Vaud). The novelty of this device is that it is a 3 degrees of freedom desktop system, supporting pronation/supination, flexion/extension and grasping hand movements and it is totally dedicated, in its current state, to children. The kinematics and the construction aspects of this desktop device are presented. Its different advantages are discussed to point out the benefits of this structure. Control and force feedback aspects combined with virtual reality are also presented. A prototype of the “Handreha” is realized and presented and the performances discussed. The first evaluations with hemiplegic children really show that the mechanical design of the device fits the targeted specifications**

***Keywords*- Hand Rehabilitation; wrist; hemiplegic; children; force feedback; control; virtual reality.**

I. INTRODUCTION

Rehabilitation therapy for paraplegics, quadriplegics and hemiplegics often consists of mobilization exercises of the affected limb by a therapist (Figure 1). The exercises may have different objectives depending on the pathology. They may seek to reduce hypertonia, increase the joint range of motion, improve the plasticity behavior of the limb, increase muscular strengths, decrease spasms or attain various other objectives [1] [2]. This conventional mode of therapy gives good results, but it is severely limited by the fact that a therapist is needed for each single patient during the total period of exercise. Increasingly, the cost of this to the health care system is enormous, and the need for therapy far exceeds the availability of trained therapists.

Currently available rehabilitation devices are robot-like structures [3][4][5][6][7]. Two examples are illustrated in Figure 2 for both lower limbs (the MotionMaker) and upper limbs (Armeo).

Figure 1. Therapist moving the fingers of a hemiplegic child (Kawahira method [8])

The robotized devices provide repetitive, precise and totally instrumented mobilization of the limbs.

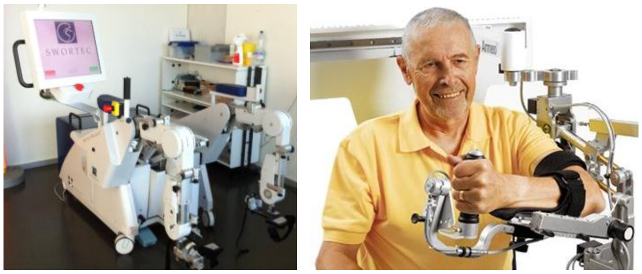


Figure 2. Examples of Rehabilitation robots: (Left) The MotionMaker for lower limbs [9], (Right) The ARMEO for upper limbs [5].

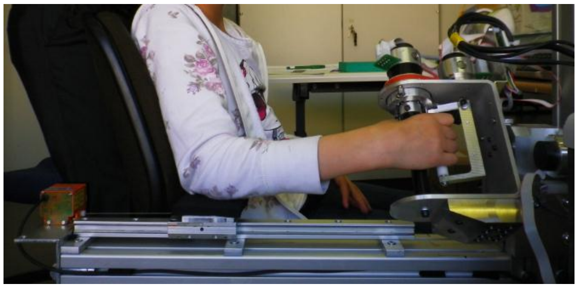


Figure 3. **Handreha**: The developed desktop hand rehabilitation device

In this paper, we are interested in the task of hand and wrist rehabilitation and we will present the developments of a 3 degrees of freedom (DOF) robot: the “Handreha”, developed at the EPFL (Figure 3) thanks to the interest and at the request of the "Neurology and Pediatric Neuro-Rehabilitation" Service of the CHUV hospital. The novelty of this device is that it is desktop system, supporting pronation/supination, flexion/extension and grasping hand movements and it is totally dedicated, in its current state, to children.

"Handreha" has been developed for hand rehabilitation of hemiplegic children from 7 to 14 years old. The other aspect of this work presented in the section IV-B is the development of a virtual labyrinth game with haptic force feedback. The objectives of the game are motivating the children and keeping them using the rehabilitation exercises.

II. OVERVIEW OF SOME HAND REHABILITATION DEVICES

Haptic interfaces allowing force feedback are required in order to improve interaction through a virtual environment. Several devices have been developed. However, these interfaces are mostly focused on the rehabilitation of the shoulder and the arms, but not the hand. There are more hand rehabilitation systems based on "gloves" [11] [12] [13]; but, unfortunately, even if they are more accurate, they are more complex and expensive (Figure 4-Right).

The HWARD (Figure 4-Left) focuses on the rehabilitation of the hand only. It is a robot with 3 DOF for the movement of the fingers, thumb and flexion / extension of the wrist. It can assist the patient in grasping real objects without any virtual reality support. This is not a haptic system but one of the only hand rehabilitation robots developed until now [14].

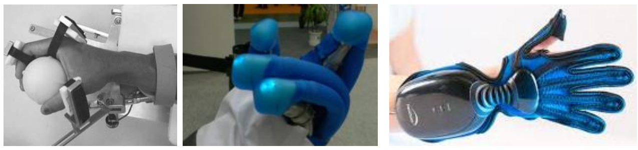


Figure 4. Hand Rehabilitation: (Left) the HWARD, (Mid) The hand glove from Panasonic, (Right) Hand glove HandTutor [13]

The Gentle/G (Figure 5) allows the rehabilitation of the arm, shoulder and hand. The movements of reaching and grasping are exercised through a 6 active DOF and 3 passive DOF: 3 DOF for positioning the active arm, 3DOF passive positioning of the hand and 3 DOF for the assets reaching movement. This robot anthropometric settings [16]. Other similar systems are the "Robotherapist" presented in [17] and [18] and the Armin [5] (Figure 2) commercialized under the name of ARMEO by the company Hocoma (CH).

Figure 5. The Gentle/G system during a rehabilitation exercise

As we previously noticed, other different devices exist and are more dedicated to the rehabilitation of the entire upper extremities.

Here are some examples.

- The MIME device that is built using a PUMA robot for a 6 DOF hand rehabilitation [19].
- The MIT-Manus [20] which is now commercialized by the company Inmotion. A new variant provides the flexion/extension and pronation/supination movements and also the radial and ulnar deviations of the wrist.
- The HENRIE uses the robot Haptic MASTER (3 DOF) for arm rehabilitation. A supplementary passive grasping DOF (spring based) is added. Thus, the stiffness of the "virtual object" felt is constant. With the Haptic MASTER, the weight of the object is felt on the wrist [21].
- The SEAT (Figure 6) for arm rehabilitation uses a steering wheel for the measurement of the applied force applied by each arm (left and right). It is equipped with a motor that assists the plegic member or makes it work longer due to the application of a resistant torque [22].

Figure 6. The SEAT System

- Another interesting device (Figure 7) is the ReHapticKnob developed by the RELAB [26]. It is a 2 degrees of freedom desktop and compact device that may be used for the assessment and therapy of grasping. It provides both pronation/supination and grasping movements.

Figure 7. The ReHapticKnob

III. THE MECHANICAL DESIGN OF THE "HANDREHA"

A. *Objectives*

The principal objectives of our development have been to develop a light desktop, three DOF hand rehabilitation device for hemiplegic children. Each degree of freedom is actuated and the device is able to be used for haptic purposes and interfaced with virtual reality environments.

The 3 supported degrees of freedom are as follows (Figure 8):

- The rotation of the forearm (Rx) over 180°, namely the pronation / supination.
- The orientation of the hand (Rz) over 180°, namely the flexion / extension of the wrist.
- The grasping motion (Θ) over 60° that allows opening and closing of the gripper.

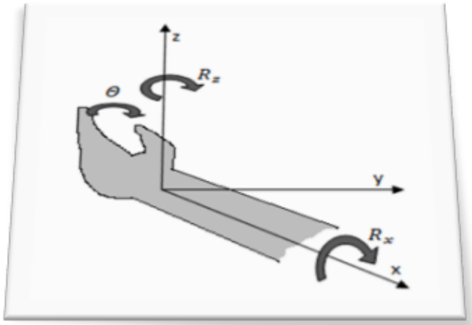


Figure 8. Required degrees of freedom of the HANDREHA device

This paragraph presents the haptic interface Handreha device developed by EPFL Its development has been motivated by the availability of a cost-affordable desktop device designed for hemiplegic children. Both "**rehabilitation**" and **"assessment"** purposes have been targeted. The progress in wrist capabilities by increasing the motion, force and coordination are the principal objectives of "HANDREHA".

Handreha can be positioned on a table and may be configured for the right hand as well as for the left hand.

All the joints are motorized and instrumented with position incremental encoder sensors to allow controlled force/position feedback.

B. *Anthropomorphic requirements*

Prado-Leon et al. [24] surveyed anthropometric data of Mexican children. Linghua et al. [25] also measured anthropometric data of Chinese children. Table III and Table IV, respectively, summarize this data in the Appendix A.

Nevertheless, we also carried out a series of anthropomorphic measurements conforming to our required objectives which concern the tasks of flexion/extension and grasping (Figure 9). These measurements are compiled in the (Table I). 9 children were implicated in this series of measurement to comfort the literature data.

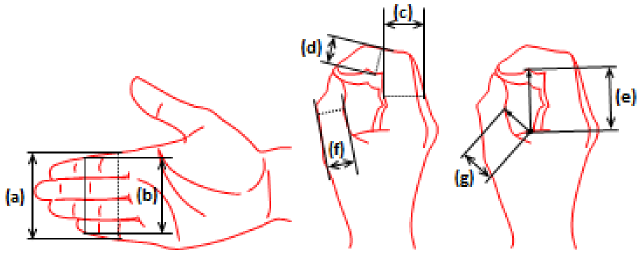


Figure 9. Anthropomorphic measured parameters

TABLE I. ANTHROPOMETRIC MEASURED HAND PARAMETERS

Dimensions (mm)		Subject	A	B	C
		Age (y/o)	6	7	9
Finger	Breadth at proximal	**(a)**	51	53	58
	Breadth at middle	**(b)**	47	51	52
	Thickness at proximal	**(c)**	19	21	21
	Thickness at middle	**(d)**	15	15	15
	Length to DIP from MP	**(e)**	33	38	39
Thumb	Thickness	**(f)**	15	14	16
	Length to IP from MP	**(g)**	18	20	19

To develop "Handrea", our desktop device for hemiplegic children from 6-14 yo, we decided to adopt the following parameters (Table II). For h and i parameters see Figure 10.

TABLE II. ANTHROPOMORPHIC HAND REQUIREMENTS

Dimensions (mm)			
Finger	Breadth at proximal	**(a)**	50-75
	Breadth at middle	**(b)**	45-70
	Thickness at proximal	**(c)**	18-25
	Thickness at middle	**(d)**	15-20
	Length to DIP from MP	**(e)**	30-45
Thumb	Thickness	**(f)**	15-25
	Length to IP from MP	**(g)**	18-30
Elbow	Elbow to wrist	**(h)**	150-300
	Elbow to ground	**(i)**	450-600

Figure 10. Seating configuration and parameters (Table II)

C. *Ergonomic requirements*

The grasping mechanism has been chosen to be closest to scissors principle (Figure 11).

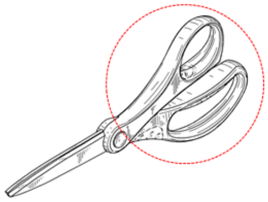
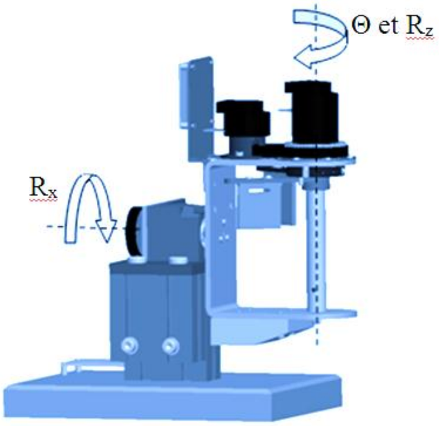


Figure 11. Scissors handling

Scissors are often used in occupational therapy (OT) and they provide more natural grasping movements than the use of simple plate type grasping.

D. *Mechanical design*

Handreha has been designed as a serial kinematics with one motor on the frame ensuring the pronation/supination degree of freedom (Rx). The other motors are on the mobile part and their movements are combined to carry out the flexion/extension and grasping (Figure 12).



6

Figure 12. The mechanical structure

In terms of torques, the joints respectively allow the permanent torques of $\boldsymbol{M_{xrms}} = \mathbf{0.2Nm}$ and $\boldsymbol{M_{zrms}} = \boldsymbol{M_{grasp\_rms}} = \mathbf{0.3Nm}$ (which corresponds to a grasping force of **4N** or 400 gram-forces).

Children with Hemiplegia may have muscle spasms and this leads to the possibility of the presence of radial and axial transient forces of up to 25 [N].
There is no need for fast motions. The maximal required velocity is around 10 rpm (180° per 3 seconds). The maximal acceleration is 20 rpm/s/s (assuming that we reach the maximal velocity in 0.5s).

This structure can be divided into two parts. The first is the rotation of the forearm and the second is the grabbing system composed of the two other movements. As we can observe, the grasping motion is coupled to the rotation of the wrist around the z-axis.

1) *The rotation of the forearm*

The 180° rotation of the forearm is simply realized by one active pivot driven by a Maxon EC45 motor with a belt transmission assuring a convenient gearing to make available the required torque.

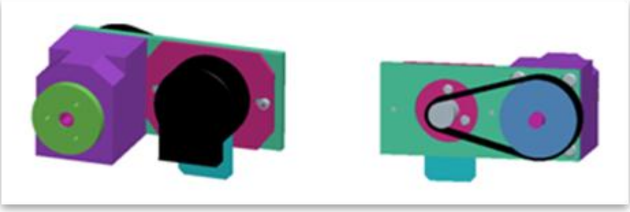


Figure 13. The rotation of the forearm

2) *The grabbing system*

The grabbing system (hand orientation and the grabbing movement), is composed of two active rotations. The first (the hand orientation Rz) is driven by motor number 2 (Figure 14 and Figure 15). This motor drives the stator of motor number 3 through a belt. In order to transmit this rotation to the hand of the hemiplegic child, two arms forming a gripper are fixed to the stator of motor 3 (stator arm) and also to the rotor of motor 3 (rotor arm). Therefore, when the hand of the child turns with a fixed angle of aperture, both arms move simultaneously.

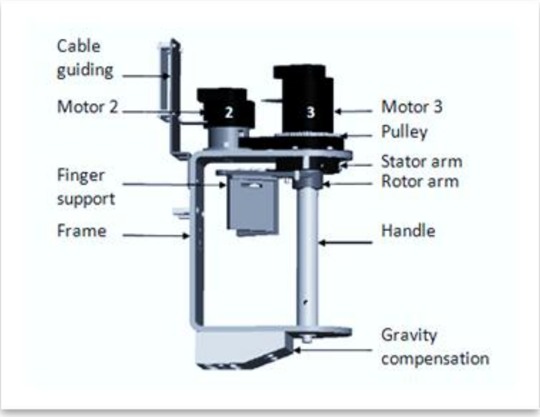


Figure 14. The grabbing system details with the previous version of Handreha

As for the grabbing movement, it is driven by motor number 3 through planetary gearing. Thus, when the child closes or opens its hand, only the rotor of motor number 2 moves.

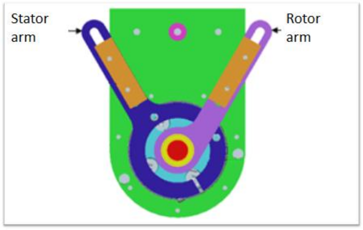


Figure 15. The grabbing system

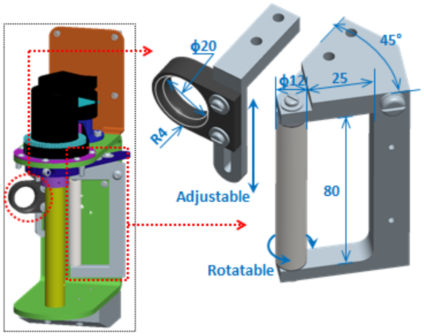


Figure 16. The new grabbing system of Handreha **conforming to the scissors principle**

IV. REALIZATION AND CONTROL OF HANDREHA

A. *The prototype*

The photos below show the HANDREHA prototype. This prototype is intended to be fixed on a table to allow mobilization through a force feedback emulation using a virtual reality application and different interaction models.

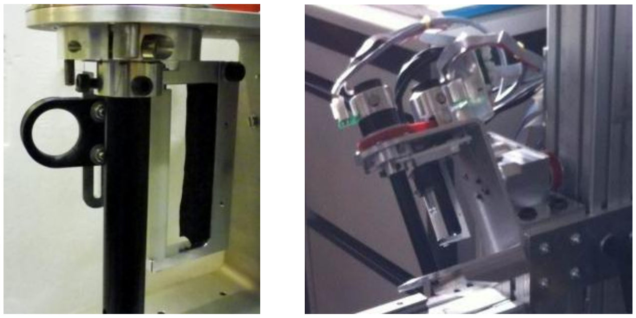


Figure 17. The prototype of HANDREHA

The device has been mounted on a mobile frame to allow its use for clinical trials. This also has the advantage of having the electronics on the frame.

This frame allows the adjustment of the elbow rest to conform to the seat height (Figure 18). Another interesting aspect which has been considered is the securing of the elbow movements by guiding it (the elbow) through a linear movement in the direction of the pronation axis. This totally removes the elbow compensation movements in flexion/extension of the wrist (Figure 20).

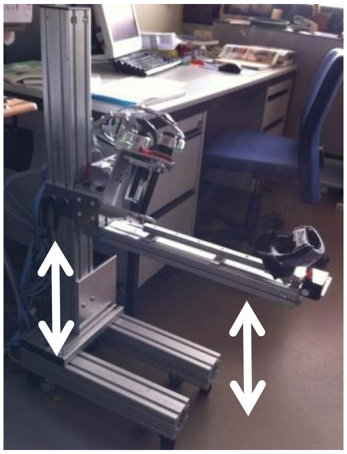


Figure 18. Mobile frame and height adjustment

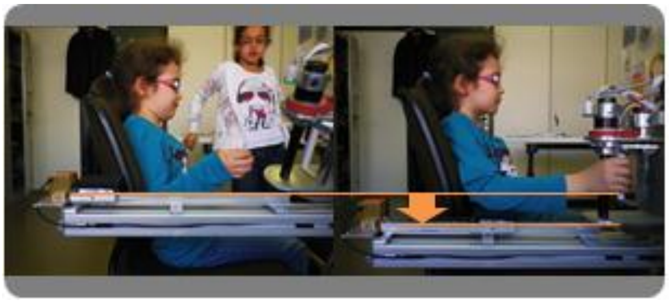


Figure 19. Elbow rest Height adjustment with a 7 years girl

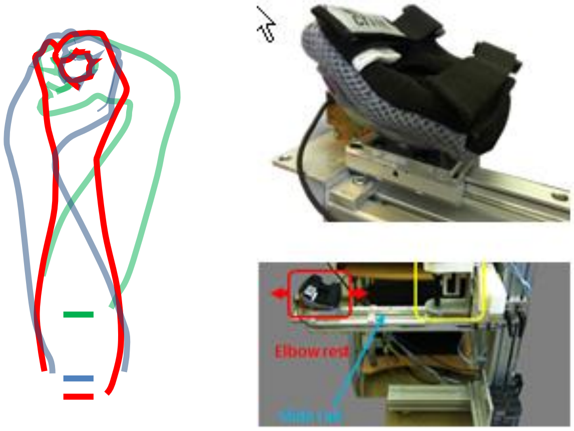


Figure 20. Elbow rest guiding to avoid compensating movements in flexion

B. *The controller and the virtual application*

The controller has to impose the values of applied torques by each motor at each joint and ensures a desired behavior (stiffness, linear or nonlinear viscosity, …) with respect to a chosen environment.

This is carried out both by the servo-amplifier of the motors that are configured in torque mode (the torque mode bandwidth is 1 KHz) and an additional virtual application. The virtual application sets up the desired force behavior which is function of the measured joint positions and velocities each 1 ms (Figure 21). More details concerning this PC based open controller may be found in [26].

To be effectively adapted to manipulation by children and motivate them to use the haptic device, a dedicated application has been developed. This application is based on a virtual labyrinth with different geometric configurations.

This application is associated with force feedback implemented both in the grasping operation (by implementing different grasping viscoelastic effects) and when moving inside the labyrinth (by implementing different viscoelastic effects during the motion in the labyrinth and by simulating the stiff contacts with the walls).

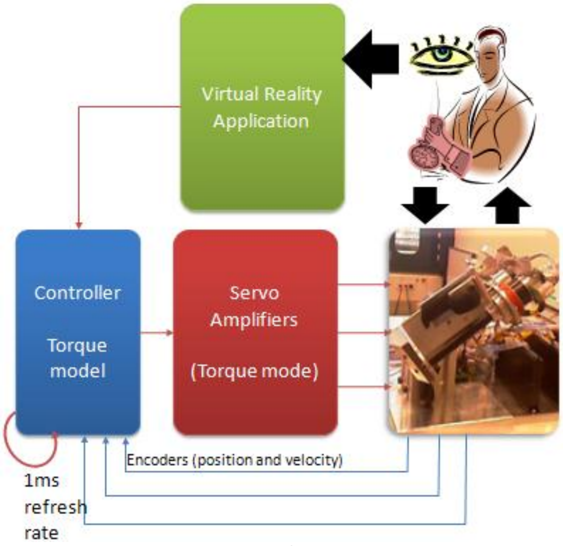
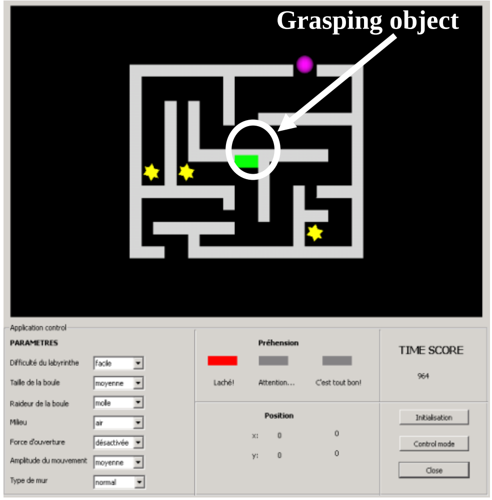


Figure 21. The haptic force control concept

The child has to grasp a ball and manipulate it through the paths of the labyrinth to reach a target allowing the child to increase its score. The configurations correspond to different levels of difficulty (Figure 23), allowing different corresponding wrist angular positions.



PARAMETRES
Difficulté du labyrinthe: facile
Taille de la boule: moyenne
Raideur de la boule: molle
Milieu: air
Force d'ouverture: désactivée
Amplitude du mouvement: moyenne
Type de mur: normal

TIME SCORE
964

x: 0 0
y: 0 0

Figure 22. The Virtual Labyrinth

To manage the grasping effect, the child has to decrease the diameter of the ball by tightening (more or less) the gripper to pass through the obstacles.

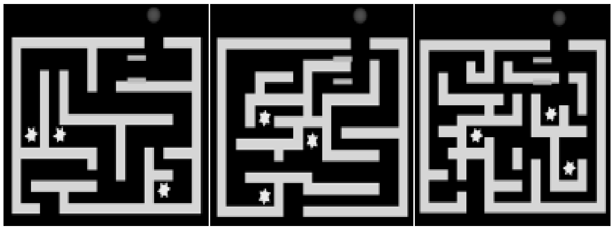


Figure 23. Different labyrinth difficulties

Figure 24 shows a healthy child manipulating the HANDREHA by playing the "Labyrinth game".

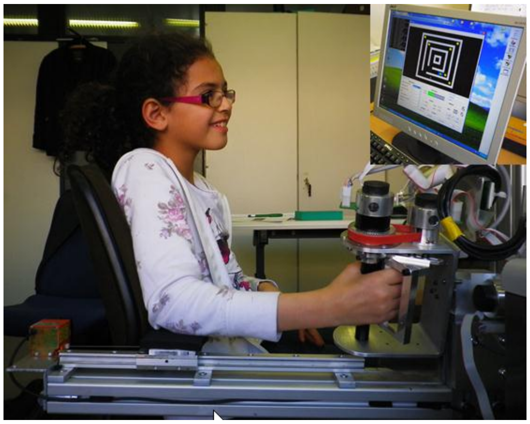


Figure 24. A 9 years sound children manipulating the Handreha

The ball is manipulated through the paths of the 2D labyrinth and a coordinate transformation is carried out to transform the rotation movements Rx and Rz into translational movements (respectively forward-straight / back-straight and forward-right / forward-left). Different wall effects are also available to differentiate the sensations and make the game more attractive.

A first clinical trial of the device was carried out with three hemiplegic children (7, 10 and 12 years) at the service of "Unité de Neurologie et Neuroréhabilitation Pédiatrique, Hôpital Nestlé CHUV, Switzerland" to check the mechanism and the dimension parameters. All the manipulated variables (maximum torques, articular angles, velocities, scores) have been saved in a database in order to carry out a systematic and a quantified progress of the capabilities during the exercises. These tests have concluded to the improvements proposed in the current paper.

V. CONCLUSION

This paper presented the mechanical development of "HANDREHA", a hand and wrist haptic device for hemiplegic children. This device has been particularly developed as desktop robotic system and provides three degrees of freedom: pronation/supination, flexion/extension and grasping. Force feedback aspects have also been considered to enlarge the implementation of different rehabilitation strategies.

HANDREHA is an academic prototype developed by the Laboratory of Robotic Systems (EPFL). It is an affordable device and very flexible in terms of adaptation to desktop applications and for hospital clinical therapeutic evaluations. It is adapted for children from 7 to 14 years old and allows elbow rest height adjustment and configuration of hand parameters. The elbow compensation movement is totally removed trough guided elbow movement.

It is now at the hospital CHUV of the Canton of Vaud in Lausanne and a second series of clinical trials is programmed. These tests will use the developed application for tests with different hemiplegic children.

REFERENCES

[1] A. Joel DeLisa, Physical Medicine and Rehabilitation: Principles and Practice, 4th edition, 2100 pages, 2004.

[2] H. Janet Carr, and B. Roberta, Neurological Rehabilitation: Optimizing Motor, 364 pages, 2003.

[3] J. Stein, R. Harvey, R. Macko, C. Winstein, and R. Zorowitz, Stroke Recovery and Rehabilitation, Ed Demos MEDICAL, 797 pages, 2009.

[4] P. Métrailler, V. Blanchard, I. Perrin, R. Brodard, R. Frischknecht, C. Schmitt, J. Fournier, M. Bouri and R. Clavel, Improvement of rehabilitation possibilities with the MotionMaker™, The first IEEE / RAS-EMBS International Conference on Biomedical Robotics and Mechatronics, BioRob, Pisa Italy, 2006,

[5] T. Nef, M. Mihelj, and R. Riener, ARMin: A robot for patient-cooperative arm therapy, Med. Biol. Eng. Comput., Vol. 45, pp. 887–900, 2007.

[6] C. Schmitt, P. Métrailler, A. Al-Khodairy, R. Brodard, J. Fournier, M. Bouri, and R. Clavel, The Motion Maker™: a Rehabilitation System Combining an Orthosis with Closed-Loop Electrical Muscle Stimulation, 8th International Workshop on Functional Electrical Stimulation, pp. 117-120, Vienna Austria, 2004.

[7] G. Charles Burgar, S. Peter Lum, C. Peggy Shor, and H.F. Machiel Van der Loos, Development of robots for rehabilitation therapy: The Palo Alto VA/Stanford experience, Journal of Rehabilitation Research and Development,Vol. 37 No. 6, pp. 663-673, 2000.

[8] K. Kawahira, M. Shimodozono, A. Ogata, and N. Tanaka, Addition Of Intensive Repetition Of Facilitation Exercise To Multidisciplinary Rehabilitation Promotes Motor Functional Recovery Of The Hemiplegic Lower Limb, J Rehabil Med; Vol 36, pp. 159–164, 2004.

[9] Y. Stauffer, Y. Allemand, M. Bouri, J. Fournier, R. Clavel, P. Métrailler, and R. Brodard, Clinical trials with the WalkTrainer: Preliminary results, Journal of Biomechanics, Volume 41, pp. S136-S136, 2008.

[10] Y. Stauffer, M. Bouri, C. Schmitt, Y. Allemand, S. Gnemmi, J. Fournier, R. Clavel, P. Métrailler, and R. Brodard, Cyberthèses, Mise en œuvre d'un nouveau concept de rééducation pour paraplégiques et hémiplégiques, Journal Européen des systèmes automatisés, vol. 41, num. 2, pp. 261-278, 2007.

[11] P. C. Kung, C. K. Lin, M. S. Ju, Neuro-rehabilitation robot-assisted assessments of synergy patterns of forearm, elbow and shoulder joints in chronic stroke patients, Clinical Biomechanics, Volume 25, Issue 7, pp. 647-654, 2010.

[12] T. Markow, T., Ramakrishnan, N., Huang, K., Starner, T., Eicholtz, M.; Garrett, S., Profita, H., Scarlata, A., Schooler, C., Tarun, A., Backus, D., Mobile Music Touch: Vibration stimulus in hand rehabilitation,Pervasive Computing Technologies for Healthcare (PervasiveHealth), 4th International Conference, Munich, 2010.

[13] E. Carmeli, J. J. Vatine, S. Peleg, G. Bartur, and E. Elbo, Upper limb rehabilitation using augmented feedback: Impairment focused augmented feedback with HandTutor, Virtual Rehabilitation International Conference, pp 2200-2202, Israel, 2009.

[14] C. D. Takahashi, L. Der-Yeghiaian, A robotic Device for hand motor therapy after stroke. IEEE 9th international conference on rehabilitation robotics, pp. 17-20, USA, 2005.

[15] L. A Malone, P. L Gervaisb, R. S Burnhamc, M. Chanc, L. Millerd and R. D. Steadwardb, An assessment of wrist splint and glove use on wheeling kinematics, Clinical Biomechanic, Volume 13, Issue 3, pp. 234-236, 1998.

[16] R. C. V. Loureiro, and W. S. Harwin, Reach and grasp therapy: Design and control of a 9-DOF robotic neuro-rehabilitation system, IEEE 10th international conference on rehabilitation robotics, pp. 757-763, Netherlands, 2007.

[17] K. Oda, T. Kikuchi, Y. Ohyama, S. Isozumi, K. Tamida, and J. Urusho, Improvement of Mechanism of Upper Extremity Exercise Support System "Robotherapist" and Development of Application Software, IEEE International Conference on Robotics and Biomimetics (Robio), pp. 2515-2520, China, 2009.

[18] J. Furusho, N. Shichi, X. Hu, T. Kikuchi, K. Nakayama, C. Li, Y. Yamaguchi, A. Inoue and U. Ryu, Development of a 6-DOF Force Display System with High Safety and its Application to Rehabilitation, Proceedings of the 2006 IEEE International Conference on Mechatronics and Automation, pp. 962-967, China, 2006.

[19] P. S. Lum, C. G. Burgar, P. C. Shor, M. Majmundar, M. Van Der Loos, Robot-Assisted Movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke. Arch Phys Med Rehabil; Vol 83, pp. 952-957 , 2002.

[20] H. I. Krebs, B. T. Volpe, D. Williams, J. Celestino, S. K. Charles, D. Lynch, and N. Hogan, Robot-Aided Neurorehabilitation : A Robot For Wrist Rehabilitation, IEEE Trans. On Neural Systems And Rehabilitation Engineering, Vol. 15, No. 3, pp. 327-335, September 2007.

[21] M. Mihelj, J. Podobnik, and M. Munih,. HEnRiE – Haptic Environment for reaching and grasping exercise. 2nd IEEE International conference on biomedical robotics and biomechatronics, pp. 907-912, USA, 2008.

[22] M. J. Johnson, H. F. M. Van der Loos, C. G. Burgar, and L. J. Leifer, Driver's SEAT : Simulation environment for arm therapy. ICORR international conference on rehabilitation robotics, Stanford, USA, 1999.

[23] J. C. Metzger, O. Lambercy, D. Chapuis, and R. Gassert, Design and Characterization of the ReHapticKnob, a Robot for Assessment and Therapy of Hand Function, in Intelligent Robots and Systems Conf, pp. 3074-3080, San Francisco, CA, USA, 2011..

[24] L. Prado-Leon, R. Avila-Chaurand, and E. Gonzalez-Munoz, Anthropometric study of Mexican primary school children, Applied Ergonomics, Vol. 32, pp. 339-345, 2001.

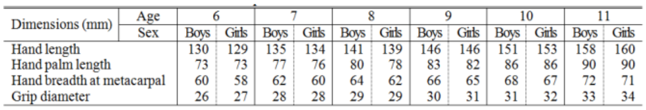
[25] L. Ran, X. Zhang, C. Chao, T. Liu, and T. Dong, Anthropometric Measurement of the Hands of Chinese Children, Digital Human Modeling, HCII2009, LNCS5620, pp. 46-54, 2009.

[26] M. Bouri, and R. Clavel, A Windows PC based robot controller: An open architecture. International Symposium on Robotics, Tokyo, Japan, 2005.

VI. APPENDIX

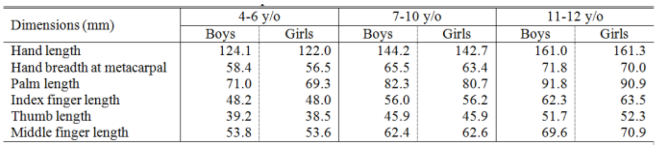
A. *Hand Anthropomorphic data (in mm)*

TABLE III. ANTHROPOMETRIC HAND DATA OF MEXICAN CHILDREN [24]



Dimensions (mm)	Age	6		7		8		9		10		11	
	Sex	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Hand length		130	129	135	134	141	139	146	146	151	153	158	160
Hand palm length		73	73	77	76	80	78	83	82	86	86	90	90
Hand breadth at metacarpal		60	58	62	60	64	62	66	65	68	67	72	71
Grip diameter		26	27	28	28	29	29	30	31	31	32	33	34

TABLE IV. ANTHROPOMETRIC HAND DATA OF CHINESE CHILDREN [25]



Dimensions (mm)	4-6 y/o		7-10 y/o		11-12 y/o	
	Boys	Girls	Boys	Girls	Boys	Girls
Hand length	124.1	122.0	144.2	142.7	161.0	161.3
Hand breadth at metacarpal	58.4	56.5	65.5	63.4	71.8	70.0
Palm length	71.0	69.3	82.3	80.7	91.8	90.9
Index finger length	48.2	48.0	56.0	56.2	62.3	63.5
Thumb length	39.2	38.5	45.9	45.9	51.7	52.3
Middle finger length	53.8	53.6	62.4	62.6	69.6	70.9