RiE 2015

6th International Conference on
Robotics in Education

Yverdon-les-Bains, Switzerland, 20 - 23 May 2015

Jean-Daniel Dessimoz, Richard Balogh, David Obdržálek, editors

ISBN: re proceedings

Technology intervention in neurorehabilitation - A practical approach to teaching

Asif Hussain[1], Paolo Tommasino[1], Charmayne Hughes[1], W.G. Kumudu C. Gamage[1], Wayne Dailey[1,2], Etienne Burdet[2], Domenico Campolo[1]

[1] School of Mechanical and Aerospace Engineering,
Nanyang Technology University, Singapore.
[2] Bioengineering Department,
Imperial College of Science, Technology and Medicine, United Kingdom.

***Abstract*—the aging population and an increase in the demand for post injury therapy has generated particular interest in technology based solutions for neurorehabilitation. This paper presents a practice based approach for teaching design of technology for post-injury training of motor-functions. The content of the course and its implementation using designed 2-DOF planar robot are discussed here.**

Keywords: neurorehabilitation; rehabilitation; mechatronics; design; robotics

I. INTRODUCTION

Neurorehabilitation is becoming an important area of research. Due in part to an ageing population, an increasing number of people are affected by neurological injuries (e.g. stroke, multiple sclerosis, Parkinson disease) resulting in sensorimotor disabilities. For instance, stroke (also referred to as a cerebrovascular accident) is the leading cause of disability for adults in the developed countries. It is estimated that the stroke affected population will increase further by 30% between 2000 and 2025 [1].

The high demand for physical therapy after neurological injuries has generated particular interest in using technology assisted systems for rehabilitation with the objectives to decrease the therapist's workload and facilitate training with minimal supervision at an affordable cost. Different types of technology-based solutions have been proposed in recent decades and have shown promising results [2]–[5]. However teaching/training students interested in technology based approach to neurorehabilitation remains a difficult challenge as designing an effective rehabilitation system demands input from multiple fields, including human centered mechatronics (the synthesis of mechanical, electronics, and computer science design) and medicine [6]. Furthermore, time constraints make it difficult to incorporate all the factors in a semester of graduate studies.

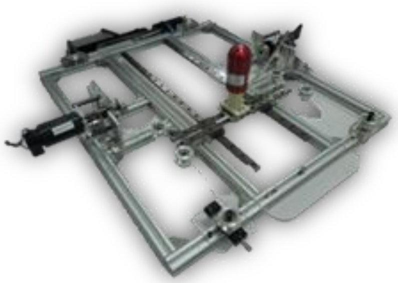

Figure 1: A planar two degrees of freedom end effector robot, H-MAN.

From a practical perspective, one possible approach for introducing a technology based neurorehabilitation course for graduate students is by adopting currently available rehabilitation systems. Robots such as MIT-Manus can serve as a basic platform and guide for students to investigate and implement different components of an effective rehabilitation regime [7]. However, most current systems are very expensive and they are generally not affordable for use in an educational environment.

At Nanyang Technology University (NTU) we have developed a low cost, portable actuated system for training horizontal arm movements, hereafter named H-MAN (figures 1 and 2). Its simple design is particularly suitable for rehabilitation in decentralized environments, such as patient’s home or in small clinics. In this paper we present how the H-MAN can be used as an effective tool for teaching technology interventions for neurorehabilitation. The following section of the paper provides an overview of the H-MAN device followed by a detailed description of the course.

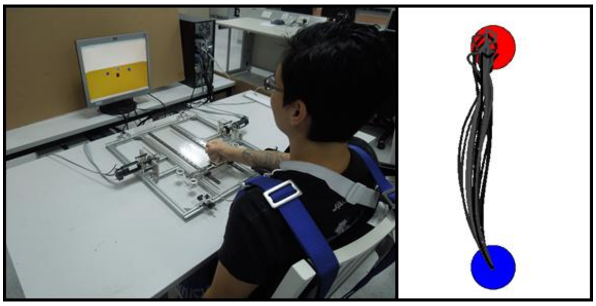

Figure 2: (Left) a participant using H-MAN for training reaching tasks. (Right) Position data collected from HMAN as the subject moves from start to final position.

II. H-MAN - Overview

H-MAN is a compact, portable planar robot designed for the rehabilitation/training of arm planar movements (see figures 1 and 2). It can provide forces of up to 30 N at the end-effector (handle) in any specified direction on a planar surface to assist or resist the motion of the user and can be easily built using off the shelf components. The reader is referred to [8] for a detailed description of H-MAN hardware.

Here we discuss H-MAN from a software perspective. For teaching purposes, the H-MAN software interface is divided into three independent units: 1) the workstation, 2) the real-time controller, and 3) the display unit. Each one of them can be further divided into independently programmed sub-units (figure 3). This modular approach is particularly desirable for teaching/learning about the different components of rehabilitation devices without worrying about the whole setup. This also allows groups of students (with different backgrounds) to work in parallel on different components of rehabilitation. The functionality of each unit (sub-unit) is discussed in the following paragraphs.

The user interface is a graphical environment to facilitate participant interaction with H-MAN. It is used for selecting appropriate therapy or assessment routine relevant to each patient. It can also be used to provide feedback regarding performance improvement from previous and current sessions. For H-MAN, the framework for the user interface is programmed on the workstation (PC) using MATLAB's graphical user interface (GUI-Guide tool). The interface serves as the front end for the H-MAN system.

An algorithm is responsible for adapting the H-MAN controller in accordance with the performance of the user. For this purpose it uses the information from the user interface and performance of the participants during the previous trial(s). Various algorithms can be implemented based on the therapy requirements and or preference such as those used in other robotic therapy platforms [9], [10]. The workstation passes this information to the real-time control unit to update the control policy.

The real time controller is responsible for controlling the behavior of H-MAN in real time during a trial. Currently the controller is implemented on Quanser QPIDe (Quanser Inc.). As with the adaptation algorithm, the implemented real time controller can be altered depending on the requirements. For example, it can be a simple proportional-integral-derivative controller (PID) or a relatively complex assist-as-needed controller [11], [12]. In any case, the parameters of the controller can be adjusted after each trial via the adaptation algorithm. This approach is adopted to limit the amount of real time processing. This post-trial adaptation also affords the possibility to keep the controller simple, and hence allows for possibility of controller implementation using a microcontroller.

Quanser QPIDe, the real-time controller platform, communicates via transmission control protocol (TCP) with the display unit running on a PC/Mobile device/Tablet. The visual interface can be any therapy-relevant game and can be designed in any programming language and/or gaming engine. Currently the commercially available gaming engine *Unity* is used for interfacing. That said, due to the generality and widespread adoption of TCP, any graphical interface can be used.

The feedback block shown in figure 3 can manifest as many varieties of information. For example, proprioceptive feedback provided by the real-time controller in the form of a force field, or tactile feedback using external vibrators to provide haptic cues for guidance. Similarly, the display unit can be used to give visual and auditory feedback, both during and after each trial.

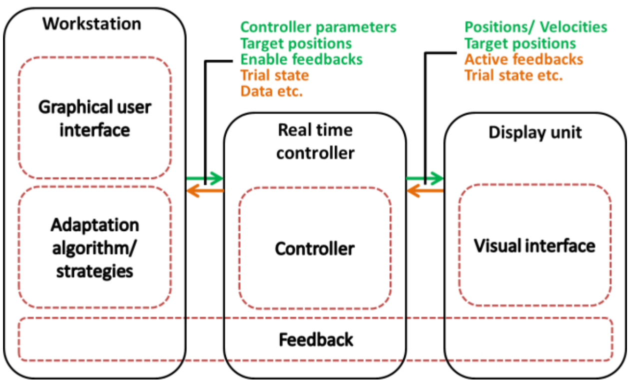

Figure 3: The H-MAN software interface is divided into three independent units, 1) the workstation, 2) the real time controller, and 3) the display unit

III. Neurorehabilitation Technology Course

The proposed neurorehabilitation technology course is designed to be an elective course (13 weeks, 2 hours of lectures plus 1 hour of tutorial sessions) for final year undergraduate and master's students at Nanyang Technology University, Singapore. The course will be offered to students with a background in Electronics, Mechatronics and Computer Engineering. During the course students will learn (through practice) how technology can be used to improve the quality and quantity of rehabilitation.

Course participants will initially attend 4-5 weeks of lectures to develop a basic understanding of neurorehabilitation, including a broad overview of the literature to date on rehabilitation and assessment using robotics, conventional approaches to rehabilitation, different feedback methods, game design for inducing motivation, etc. Students will also learn how to use H-MAN during this time (table 1).

Following the lecture sessions, students will carry out practical work for the remaining weeks. Each group (4 or 5 students per group) will work on designing a complete working rehabilitation system using the H-MAN platform followed by a

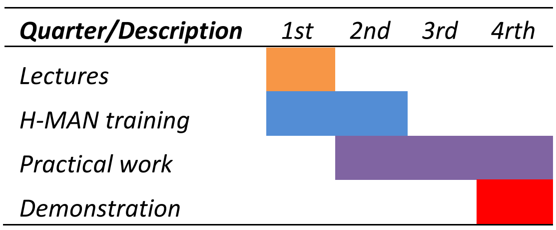

Table 1: Gantt chart giving a general overview of the course flow

final demonstration. The practical work will involve dividing work within the group based on interests and background to cover the different topics of rehabilitation; each of the main topics is briefly discussed in the following sub-sections.

A. Robotic movement control strategies

Control strategies in the rehabilitation of motor function broadly refer to how the robot and participants' limb physically interact during movement training. Multiple types of robotic strategies are used in rehabilitation, including 1) *assistive strategies*, where the participant's limb is moved in the desired manner by the robot to accomplish the task, 2) *challenge-based*, where the task is made more difficult by introducing resistive forces, 3) *haptic-simulation*, where virtual haptic fields are generated to imitate activities of daily living in a virtual environment [11]. Depending on the component of health being trained (impairment, activity and participation; defined by International Classification of Healthy and disability [13], [14]) and patient (type of injury and its severity) a version of these control strategies can be adopted.

The type of implemented control strategy can greatly affect the outcome of rehabilitation. Hence it is vital that students have a proper understanding of robotic control algorithms/strategies and their design. Students will be encouraged to implement different types of control strategies (e.g. assistive, challenge-based, haptic simulation) on H-MAN and observe their effects. Students will work on one or both the main controller and the adaptation algorithms to carry out this task.

B. Feedback strategies

Feedback strategies in rehabilitation can be broadly divided into two major types: 1) *intrinsic feedback*, which guides the subject about the task during its execution using one or combination of visual, auditory, proprioceptive, and tactile feedback components; and 2) *extrinsic feedback*, which refers to feedback to indicate the subject's performance and results [15]. Results refer to the type of skill the participant has achieved and trained for, while performance indicates the performance in the actual training exercise. Different types of approaches can be used for extrinsic feedback (e.g. computer generated verbal encouragement, charts, videos, avatars).

Choosing patient specific feedback is complex, can vary with the subject, and can greatly affect the performance of subject. Through implementation on H-Man, students will investigate which types of feedback to offer during task execution as to not distract the participants, while still guiding the subject to maintain task performance quality. Similarly, students will be encouraged to implement different methods by which task relevant results and performance parameters can be displayed.

C. Motivational Strategies

Rehabilitation professional consider motivation to be an integral component of (re)learning [16]. From a rehabilitation perspective, subjects' motivation is generally assessed on how actively they participate in the task and adhere to the rehabilitation regimen. Similarly, lack of interest during therapy relates to participants demotivation [17]. Multiple factors contribute to motivation, including personal traits, social factors, and most importantly the task itself.

From a task perspective, it is crucial that the designed task is fun and interesting for the participant. This characteristic can be achieved by designing engaging and fun games as a part of therapy, considering that that task must not be so simple or repetitive to bore the subject, nor too difficult so as to demoralize the subject. The designed task should also adapt optimally with participant performance. Furthermore, independence in selecting feedback, time of therapy and the general control over therapy induces active participation and hence motivation [15].

Students will be encouraged to design innovative interactive games (on the display unit) for H-MAN using commercially available gaming engines, with primary focus on difficulty adaptation and ease of use. Students will also implement routines to offer varying degree of independence to the participants during therapy.

D. External Sensor Integration

External sensors refer to information that is generally not directly available from the robotic systems. In the case of H-MAN information regarding the muscle activation produced by skeletal muscles which can be measured by Electromyography (EMG). This information can be useful in multiple ways. For example, EMG can be used to trigger robot-assisted motion by, based on the activity of muscles responsible for that motion [18], [19]. Other devices, such as motion capture systems and force/torque sensors, can be used to extract relevant kinematic and kinetic information, and can be used to assess and provide feedback about the performance, and/or to improve or refine the control of the robot for maximum therapeutic effects.

Students will learn to use the EMG system, and will synchronize EMG data with that obtained by the H-MAN system, in order to extract task specific information. This information will be used in order to provide feedback to the patient regarding maladaptive compensatory movements. The objective of this work will be to enhance the quality of therapy by evaluating muscle activation patterns during task performance, and/or to develop algorithms to enhance the quality of the controller to ensure optimal participation from participants.

E. Data analysis and Statistics:

Understanding how to treat data, process inspect, clean, and transform data into meaningful information for reaching conclusions is arguably the most crucial component in any form of research, and neurorehabilitation is no exception.

During the term, students will learn how to extract and analyze information gathered using H-MAN and/or other attached instrumentations (sensors). Students will learn how to define appropriate (in) dependent variables, perform parametric and non-parametric statistical analysis, and draw appropriate conclusions based on the results. Furthermore, students will learn how to interpret the significance of these results, and their contribution to the field of neurorehabilitation.

IV. Assessment Approcah

Instead of traditional exams, this course will be evaluated by a combination of practical work and submitted reports, both of which carry a weight of 50%. Students will submit a set of reports, consisting of: 1) *A critical review* where individual students will submit a report on another group project from a critical perspective i.e. they will highlight the issues and advantages of the approach adopted by the group; 2) *Rehabilitation components,* in which individual students will submit a detailed report on one of the sub-topics of rehabilitation discussed previously i.e. feedback, control strategies; and 3) *A project report,* in which each group will submit a detailed report on the complete project with details of work carried, and the adopted approach and reasons behind it.

Finally the practical part of the course marks will be assessed by the assessment of the developed complete systems (counting for 50% of the course mark, one mark by project's group) (table 2). Projects will be assessed in terms of the therapeutic relevance of the chosen design as well as its implementation by a panel of invited rehabilitation and engineering design experts. Non-specialist guests and the students themselves will also be able to assess the projects and their marks will be combined with the judges' at a reduced weighting. This approach of assessment is similar to the H-CARD course recently developed at Imperial College [6].

	Percentage	*Submission type*
Critical review	*15%*	*Individual*
Rehabilitation	*15%*	*Individual*
Project Report	*20%*	*Group*
Demonstration	*50%*	*Group*

Table 2: An overview of the course assessment

V. Conclusion

This paper presents an engaging project based approach for educating student's interested in technological solutions for neurorehabilitation using H-MAN. The planar robot provides a low-cost alternative to currently available expensive rehabilitation systems and its modular software design approach makes it potentially feasible to teach different components of technology intervention in neurorehabilitation in a semester course.

As future work we also aim to let students investigate, multiple different therapy regimes involving interaction between patients (patient-patient interaction) and or patient-physiotherapist interaction. The techniques can be implemented using a combination of H-MAN's, where each patient/physiotherapist uses an H-MAN linked to the others by a student defined algorithm that promotes learning. However details of this are not in the scope of the paper and will be discussed in future studies.

Acknowledgment

This work was partly supported by the `H-Man' project (NMRC/BnB/0006b/2013), Ministry of Health, Singapore.

References

[1] T. Truelsen, B. Piechowski-Jóźwiak, R. Bonita, C. Mathers, J. Bogousslavsky, and G. Boysen, "Stroke incidence and prevalence in Europe: a review of available data.," *Eur. J. Neurol.* 13: 581–98, 2006.

[2] G. B. Prange, M. J. A. Jannink, C. G. M. Groothuis-Oudshoorn, H. J. Hermens, and M. J. Ijzerman, "Systematic review of the effect of robot-aided therapy on recovery of the hemiparetic arm after stroke.," *J. Rehabil. Res. Dev.* 43(2): 171–84, 2006.

[3] B. R. Brewer, S. K. McDowell, and L. C. Worthen-Chaudhari, "Poststroke upper extremity rehabilitation: a review of robotic systems and clinical results.," *Top. Stroke Rehabil.* 14(6): 22–44, 2007.

[4] R. Riener, T. Nef, and G. Colombo, "Robot-aided neurorehabilitation of the upper extremities," *Medical and Biological Engineering and Computing*. 43: 2–10, 2005.

[5] S. Balasubramanian, J. Klein, and E. Burdet, "Robot-assisted rehabilitation of hand function.," *Curr. Opin. Neurol.* 23(6): 661–70, Dec. 2010.

[6] N. Roach, A. Hussain, and E. Burdet, "Learning to design rehabilitation devices through the H-CARD course: project-based learning of rehabilitation technology design.," *IEEE Pulse*. 3(6): 51–8, 2012.

[7] H. I. Krebs, N. Hogan, M. L. Aisen, and B. T. Volpe, "Robot-aided neurorehabilitation.," *IEEE Trans. Rehabil. Eng.* 6(1): 75–87, 1998.

[8] D. Campolo, P. Tommasino, K. Gamage, J. Klein, C. M. L. Hughes, and L. Masia, "H-Man: A planar, H-shape cabled differential robotic manipulandum for experiments on human motor control.," *J. Neurosci. Methods*. 235: 285–97, 2014.

[9] E. T. Wolbrecht, V. Chan, D. J. Reinkensmeyer, and J. E. Bobrow, "Optimizing compliant, model-based robotic assistance to promote neurorehabilitation," *IEEE Trans. Neural Syst. Rehabil. Eng.* 16: 286–97, 2008.

[10] H. I. Krebs, J. J. Palazzolo, L. Dipietro, M. Ferraro, J. Krol, K. Rannekleiv, B. T. Volpe, and N. Hogan, "Rehabilitation robotics: Performance-based progressive robot-assisted therapy," *Auton. Robots*. 15: 7–20, 2003.

[11] L. Marchal-Crespo and D. J. Reinkensmeyer, "Review of control strategies for robotic movement training after neurologic injury.," *J. Neuroeng. Rehabil.* 6: 20, 2009.

[12] E. Burdet, D. W. Franklin, and T. E. Milner, *Human Robotics: Neuromechanics and Motor Control*. MIT Press, 2013.

[13] N. Kostanjsek, "Use of The International Classification of Functioning, Disability and Health (ICF) as a conceptual framework and common language for disability statistics and health information systems.," *BMC public health*. 11(4): S3, 2011.

[14] World Health Organization, "Towards a Common Language for Functioning , Disability and Health ICF," *Int. Classif.* 1149: 1–22, 2002.

[15] A. A. A. Timmermans, H. A. M. Seelen, R. D. Willmann, and H. Kingma, "Technology-assisted training of arm-hand skills in stroke: concepts on reacquisition of motor control and therapist guidelines for rehabilitation technology design.," *J. Neuroeng. Rehabil.* 6: 1, 2009.

[16] N. Maclean, P. Pound, C. Wolfe, and A. Rudd, "Qualitative analysis of stroke patients' motivation for rehabilitation.," *BMJ*. 321: 1051–54, 2000.

[17] R. Colombo, F. Pisano, A. Mazzone, C. Delconte, S. Micera, M. C. Carrozza, P. Dario, and G. Minuco, "Design strategies to improve patient motivation during robot-aided rehabilitation.," *J. Neuroeng. Rehabil.* 4:3, 2007.

[18] C. Fleischer, A. Wege, K. Kondak, and G. Hommel, "Application of EMG signals for controlling exoskeleton robots," *Biomed. Tech.* 51: 314–19, 2006.

[19] Q. Zhang, R. Hosoda, and G. Venture, "Human joint motion estimation for electromyography (EMG)-based dynamic motion control.," *Conf. Proc. IEEE Eng. Med. Biol. Soc.* 2013: 21–4, 2013.