High-fidelity Part-Task Trainer of Upper Limb Disorderfor Physiotherapist Education

*NOOR AYUNI CHE ZAKARIA[1][2]
[1]Research Organization for Advance Engineering
Shibaura Institute of Technology
307 Fukasaku, Minuma-ku, Saitama-shi, 337-8570
JAPAN
ayuni8098@salam.uitm.edu.my

TAKASHI KOMEDA[1]
[1]Research Organization for Advance Engineering
Shibaura Institute of Technology
307 Fukasaku, Minuma-ku, Saitama-shi, 337-8570
JAPAN
komeda@se.shibaura-it.ac.jp

CHENG YEELOW[2]
[2]Centre of Excellence Humanoid Robots and Bio-Sensing
UniversitiTeknologi MARA
40450 Shah Alam
MALAYSIA
chengyee.low@salam.uitm.edu.my

KAORUINOUE[3]
[3]Division of Occupational Therapy
Tokyo Metropolitan University
7-2-10 Higashi Oku, Arakawa-ku, Tokyo, 116-8551
JAPAN
inoue@hs.tmu.ac.jp

Abstract: - Usage of patient simulator andpart-task trainer in the medical education field has brought significant improvement in the training of medical practitioners. Nevertheless, for training of upper limb disorder physiotherapists, traineetherapistsstill have toengage directly with real patients to gain experience for the rehabilitation of physical diseases.In this work, a high-fidelity part-task trainer that is able to reproduce stiffness of spasticity and rigidity symptoms in upper limb disorder such as post-stroke symptoms and Parkinson disease symptoms has been developed. Such part-task trainerhas been evaluated by two experienced physiotherapists towards the aim to help trainee therapists gain experience by simulation of different patient cases in a safe and intuitive learning environment.

Key-Words: Part-task trainer, Physiotherapist Education, Upper LimbDisorder,Artificial Human Arm

1 Introduction

1.1 Simulator in Education

Simulator is a computer-controlled human mannequin or parts of human body that is able to functions as human anatomy and react to the clinical procedure used during training the doctors, surgeons, nurses or therapists. Part-task trainer simulates different situation and help the trainee learn new experiences and new clinical skills.

Simulator has not only been used in education for medical practitioners [1][2], it has been applied in educating the young pilot to fly airplanes safely for decades [3] and help veterinary clinical training as well [4]. Teaching and learning in clinical field might involve many challenges as it deals with real

ISBN: 978-1-61804-164-7

patients of human or animal and simulator can be used until the students master the clinical training thus avoiding catastrophes occurrence.

There arepatient simulator that has been used in clinical training to upgrade performances and skills in surgery [5], anesthesia and some has been proven that human patient simulator is able to develop good performance of the team even in complex field such as trauma resuscitation [6]. The usages of the advanced human patient simulator encourage the team to practice high-risk-skill in free-risk environment.

However, for physiotherapist there is no high-fidelity human patient simulatorthat has been developed to help them improve their skills performance as they still engaged directly with patients to get experiences. In order to be an expert physical therapy, therapists need to have multidimensional knowledge base where one of the concepts of therapy skills is the use of touch [7]. Health Workforce Australia National Simulated Learning Project reported that fifteen of the sixteen universities frequently use simulated learning program (SLP) during their pre-clinical programs often focus on role playing/peer learning, e-learning and low fidelity mannequins. This elaborate the importance of using simulation to help young therapist practitioners gain experience thus lead to the needs of high fidelity patient simulator or part-task trainer that can provide different patient cases and the opportunity to have contact with 'patient' in safe and encouraging environment [8].

1.2 Human Arm Mechanism

In this paper, we focused on developing an artificial human upper limb for the purposed of physiotherapist pre-clinical education. Segments of human body simulator is called part-task trainer while a simulator that can provide complete human physiological response is called patient simulator [9].

Human arm around elbow joint consists of humerus bone at the upper arm and radius and ulna bone performing the forearm. Radius is the bone located on the thumb side of the hand and rotates around fixed humerus to provide pronation movement [10] as shown in Figure 1. On average people, daily activities requires forearm rotation around 100 degree [11].

Upper limb disorders leads of aches, pain, and stiffness from fingers to the shoulder area. There are various diseases in upper limb disorders that require rehabilitation such as Spasticity, Rigidity and Contracture.

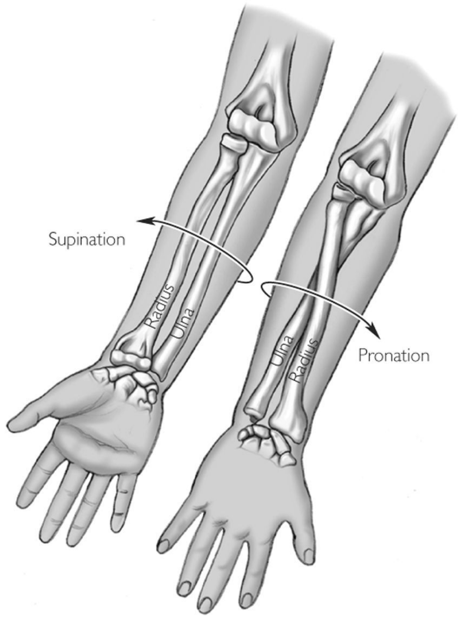

Fig. 1 Pronation movement around fix humerus bone
Jonas: Mosby's Dictionary of Complementary and Alternative Medicine. (c) 2005, Elsevier.

2 Development of Part-task Trainer

This is the second prototype where core structure of human arm is the main focus. Current prototype is able to produce themovement of the elbow joint with pronation and supination movement [12]. These movements areimportant in rehabilitation as the objective is to create part-task trainer for physiotherapist educational purposes.

The artificial human arm is build from shoulder area with angle range from -45 degree to 45 degree from horizontal plane as shown in Figure 2. By providing range of angle, physiotherapist trainees may take various postures depending on the position of the patient. Forearm is built with range of 140 degree imitating human forearm movement. Details of artificial arm is elucidate in thefollowing sections.

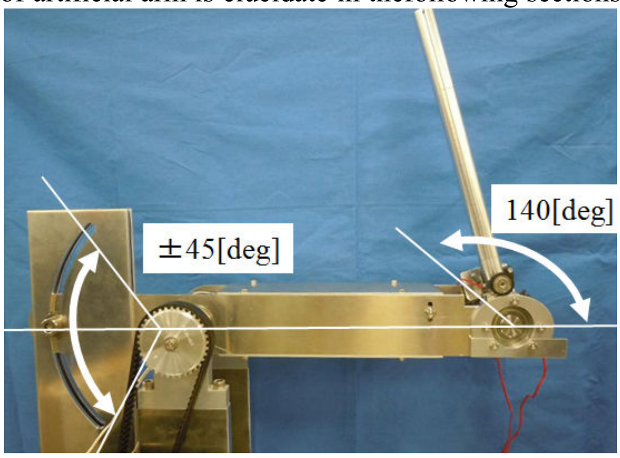

Fig. 2 Angle Range of Artificial Human Arm Simulator

2.1 Elbow Joint

Elbow joint is connected with humerus plate using cantilever mechanism of belt and pulley. Humerus is built with two plates both on the side to support the elbow joint which is the most important structure in reproducing the symptoms disorder. From the result of forearm tracking experiment in Fig. 3, we know that forearm move in ellipse movement track instead of circle track. Length of ***b*** is 7 mm longer than ***a***. Based on the first prototype evaluation, this movement is crucial as it gave different impact to the physiotherapist.

In order to produce the ellipse movement, the elbow is built with cam mechanical structure, and the ulna bone attached to the cam follower will move following the cam ellipse orbit. Figure 4 shows details of the cam shape and the position of ulna bone attached to cam follower.

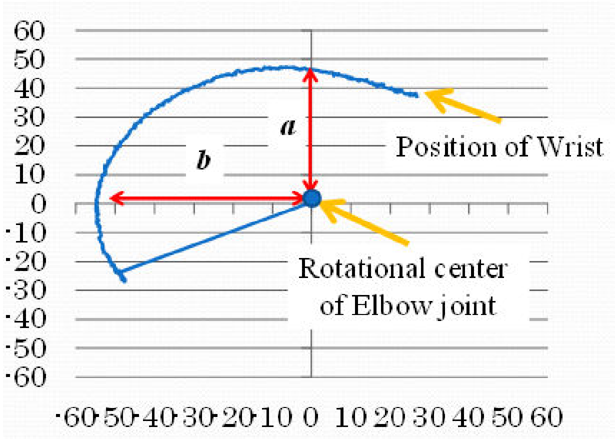

Fig. 3 Ellipse Orbit of Elbow Joint movement

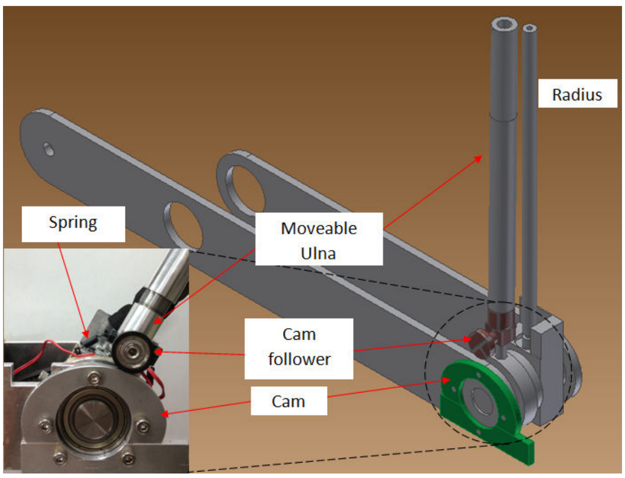

Fig. 4 Details of Elbow Joint

2.2 Forearm Structure

The ulnais built with mechanical spring structure to allow movement following the ellipse cam as in theFigure 5. Figure 5 shows thesectional drawing of radius, ulna and the elbow joint. The spring attached the fix ulna bone in the inside with the moveable ulna bone on the outside, giving the outside ulna bone ability to move freely following the cam shape in one degree of freedom.

In details, healthy human requires 50 degree of pronation and 50 degree of supination to accomplished daily activities [11]. We tried to imitate the movement of radius bone with a spherical bearing which is able to produce 30 degree angle to the artificial human arm.

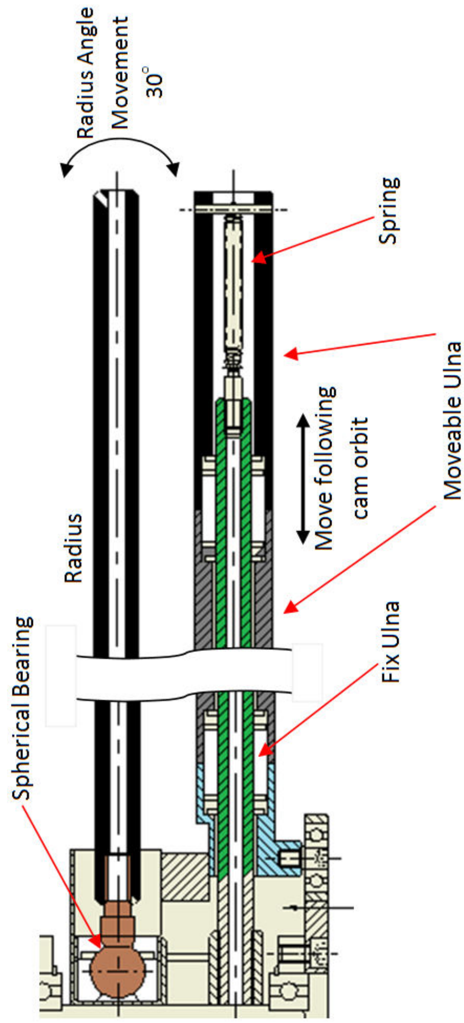

Fig. 5 Spring position for moveable ulna structure and radius angle movement

2.3 System Configuration

The part-task trainer system is built with a set of DC servo motor and a Magneto-Rheological (MR) brake to reproduce the stiffness as in patient ofupper limb disorder.MR brake is an electronic brake control system that employedbrake-by-wire system which is currently engrossed by automotive industry [13]. MR brake is a fast response compared to other hydraulic brake system. In this system, it is use to

ISBN: 978-1-61804-164-7

display resistance to the physiotherapist trainee imitating the stiffness of a patient.

At current stage, the part-task trainer is built to reproduce the symptoms of Spasticity and Rigidity. For a constant stiffness, the MR brake is used to reproduce the resistance, however for an active symptom, DC servo motor is used to support the stiffness provided by the MR brake. Details of the symptoms will be describedin Section 3: Symptoms Evaluation.

Passive force from MR brake and DC servo motor is transmitted to the elbow joint using belt and pulley as a cantilever mechanism to provide resistance following the symptoms of upper limb disorder. The passive force is activated based on the force exerted by the simulator detected by a strain gauge located at the medium of forearm while the elbow rotation angle is measured by a rotary encoder. Configuration ofthe system is shown in Figure 6.

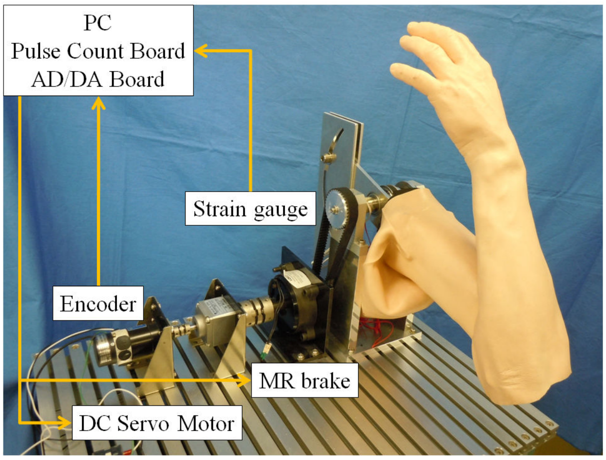

Fig. 6 System Configuration for Part-task trainer

3 Symptoms Evaluation

In order to reproduce the symptoms of upper limb disorder, database of the characteristic of each symptom need to be built. With the help of two experience physiotherapists, the characteristics of the symptoms are measured with one of the physiotherapist acted as a patient and another physiotherapist gives rehabilitation treatment. Load cell is attached to the physiotherapist to measure the force exerted by the patient. All rehabilitation sequence is recorded and analyzed with FrameDIAS to estimate the elbow joint angle.

Currently, only two symptoms are recorded; Spasticity and Rigidity. Rigidity symptoms can be characterized as Lead-pipe Rigidity and Cogwheel Rigidity. The characteristics of Spasticity, Lead-pipe Rigidity and Cogwheel Rigidity are shown in Figure 7(a), 7(b) and 7(c) respectively. There are several method under study to quantify the characteristics of upper limb disease [14] other than the Ashworth Scale [15].

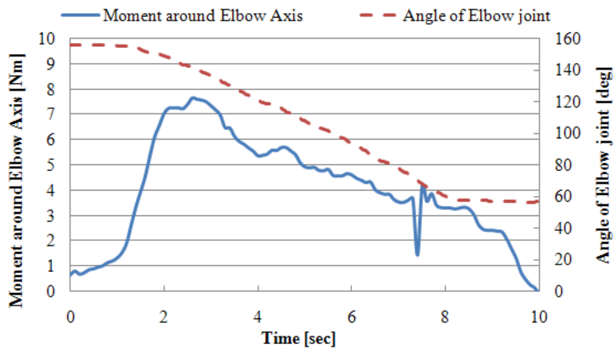

Fig. 7(a) Spasticity Characteristics

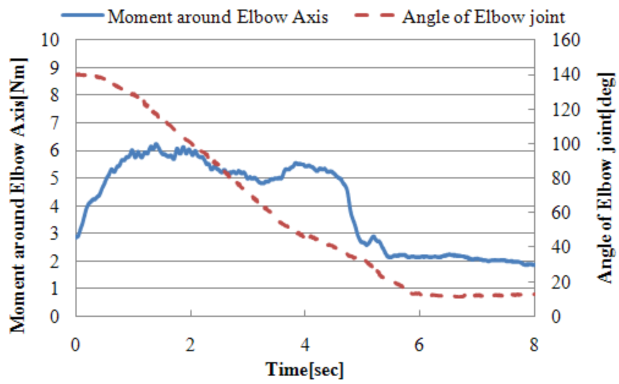

Fig. 7(b) Lead-pipe Rigidity Characteristics

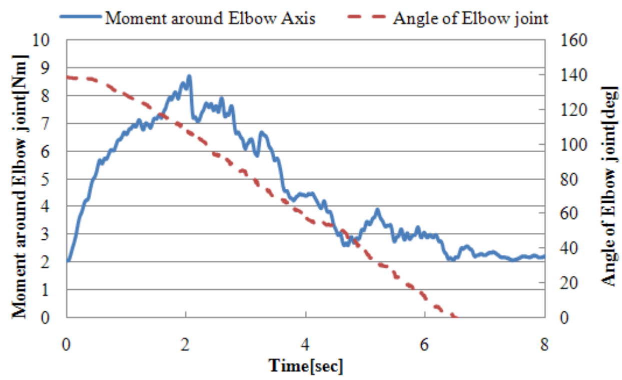

Fig. 7(c) Cogwheel Rigidity Characteristics

Spasticity is defined as velocity-dependent increased in muscle tone in response to stretch relax muscle [16] and usually can be seen in post-stroke patients. It must be assessed with a quick flexion or extension of elbow or quick pronation and supination of the forearm. Therefore, spasticity symptoms show high magnitude of moment around elbow axis during sudden extension movement from relaxed muscle tone as in Figure 7(a). Meanwhile, Rigidity symptoms are not a velocity dependent and can be seen in Parkinson Disease patients. Lead-pipe Rigidity is a continuous resistance during passive movements and ending up with sudden released of the muscle stretch [17]. The characteristics shows sudden decreased in the moment around elbow axis in Figure 7(b). Cogwheel Rigidity showing a ratchet-like-resistance during passive movement, giving symptoms of trembling of Parkinson Disease patients [17]. Characteristics of the symptom can be seen in Figure 7(c).

4 Part-task Trainer Evaluation

Using the developed upper limb part-task trainer, evaluation on the reproduce symptoms of upper limb disorder is conducted. Two experience physiotherapists evaluate the system as shown in Figure 8. The force given to the part-task trainer is detected by a strain gauge positioned at the forearm of the simulator while the rotation of the elbow axis is recorded by an encoder.

Using the evaluated symptoms characteristics, the developed part-task trainer is programmed to reproduce the symptoms. Figure 9(a) shows the characteristic of the spasticity symptoms showing an increased in moment around elbow joint especially during 120 degree of extension movement. Although we can see time delay in stiffness movement during forearm full extension, the therapist feel that it does not affect the training purpose since the important point here is the way the simulator loosen its stiffness.

Figure 9(b) shows characteristic of Lead-pipe Rigidity with continuous resistance following passive movements from therapist and sudden release of muscle where it is called 'clasp-knife' rigidity. Comparing with symptom characteristic, Lead-pipe Rigidityproduced by the develop part-task trainer shows similar symptoms with almost the same moment.

Result of the reproduce Cogwheel Rigidity symptoms by part-task trainer is shown in Figure 9(c) where we can see the ratchet-like movement during extension of forearm. The part-task trainer reproduces the trembling symptoms more details compare to the result in Figure 7(c). Symptoms evaluation is using load cell while the reproduce symptoms is measured using strain gauge.

Both the sudden moment increase symptoms in Spasticity and the continuous moment in Lead-pipe Rigidity are reproduced by MR brake while the ratchet-like movement of the muscle in the Cogwheel Rigidity is produced by DC servo motor. The constant stiffness decrease in the forearm of Cogwheel Rigidity is reproduced by MR brake.

Fig. 8 System Evaluation Experiment

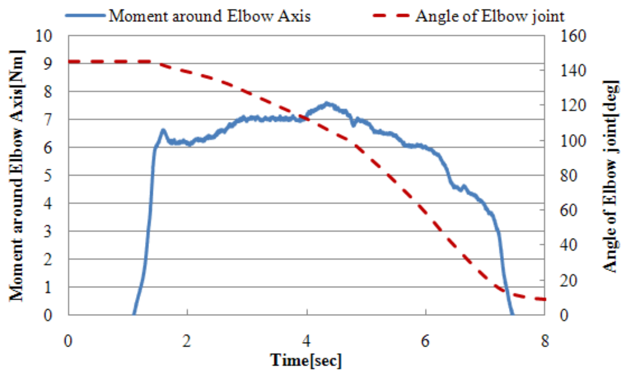

Fig. 9(a) Reproduce Spasticity

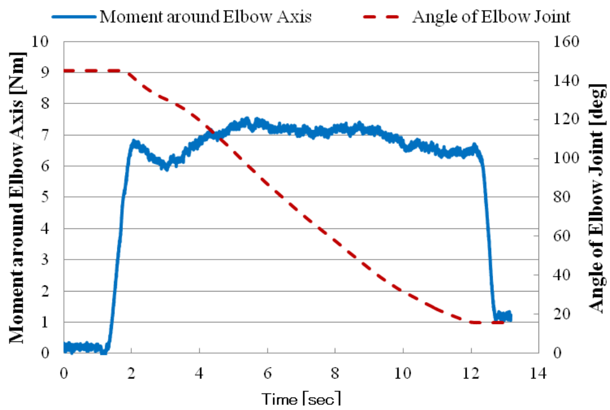

Fig. 9(b) Reproduce Lead-pipe Rigidity

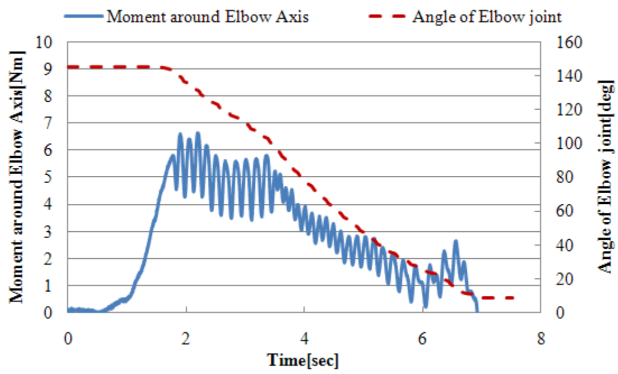

Fig. 9(c) Reproduce Cogwheel Rigidity

ISBN: 978-1-61804-164-7

5 Conclusion

Development of high-fidelity part-task trainer will help to create safe environment to the physiotherapist students and at the same time solving problem of patient availability with the increase number of students. Moreover with the existence of high-fidelity part-task trainer may increase the chances for students to engage with rare diseases and help in building clinical judgment.

Acknowledgements:
This research is carried out at the Research Organization for Advanced Engineering in Shibaura Institute of Technology, Japan. The third authorisa collaborator supported by the Ministry of Higher Education Malaysia under the grant number 600-RMI/ERGS 5/3 (23/2011).

References:

[1] Smith N, Prybylo S, Conner-Kerr T. Using human patient simulation (HPS) and standardized patients (SP) to teach electrocardiographic (ECG) rhythms: Student perceptions of learning experiences.*CardiopulmPhysTher J.* 2011;22(4):28

[2] Issenberg B, Mcgaghie WC, Petrusa ER, Lee Gordon D, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: A BEME systematic review. *Med Teach*.2005;27(1):10–28.

[3] Ruffell-Smith HP. A Simulator Study of the Interaction ofPilot Workload with Errors, Vigilance, and Decisions. *Washington, DC: National Aeronautics andSpace Administration*, 1979 p1–54.

[4] Daniel J. Fletcher, Roberta Militello, Gretchen L. Schoeffler, Catherine L. Rogers. Development and Evaluation of a High-Fidelity Canine Patient Simulator for Veterinary Clinical Training. *Journal of Veterinary Medical Education*Volume 39, Number 1 /2012pp 7-12.

[5] Hammond, Jeffrey MD, MPH; Bermann, Mordechai MD; Chen, Bo MS; Kushins, Lawrence MD. Incorporation of a Computerized Human Patient Simulator in Critical Care Training: A Preliminary Report. *Journal of Trauma-Injury Infection & Critical Care*:December 2002 Volume 53(6) pp 1064-1067

[6] John B. Holcomb, MD, Russell D. Dumire, MD, et al. " Evaluation of Trauma Team Performance Using an AdvancedHuman Patient Simulator for Resuscitation Training ". *J Trauma.*2002;52:1078 –1086.

[7] Gail M Jensen, Jan Gwyer, Katherine F Shepard, Laurita M Hack. "Expert Practice in Physical Therapy". *PhysTher*. 2000; 80:28-43.

[8] Felicity C Blackstock, Gwendolen A Jull. "High-fidelity Patient Simulation in Physiotherapy Education". *Australian Journal of Physiotherapy* 2007 Vol. 53 pp 3-5.

[9] Felicity C Blackstock, Gwendolen A Jull. High-fidelity patient simulation in physiotherapyeducation. *Australian Journal of Physiotherapy* 2007 vol. 53 pp. 3-5

[10] Eldra Pearl Solomon. *Introdution to Human Anatomy and Physiology*. 2nd Edition. Saunders 2003.

[11] Morrey BF, Askew LJ, Chao EY."A Biomechanical Study of Normal Functional Elbow Motion". *J Bone Joint Surg Am.* 1981 Jul;63(6):872-7.

[12] Noor Ayuni CZ, Cheng Yee Low, Takashi Komeda. Design of Upper Limb Patient Simulator, *Procedia Engineering*2012; Volume 41:1374–1378

[13] KeremKarakoc, Edward J. Park ,AfzalSuleman. "Design considerations for an automotive magnetorheological brake". *Mechatronics*, Volume 18, issue 8 (October, 2008),p.434-447.ISSN:0957-4158
DOI: 10.1016/j.mechatronics.2008.02.003

[14] Masaru H, Hidetoshi T, Naoichi C. "The evaluation of spasticity". *ClinRehabil* 2002. 11:1

[15] A D Pandyan, G R Johnson, C I M Price, R H Curless, M P Barnes, H Rodgers. "A Review of the properties and limitations of the Ashworth Scales as measures of Spasticity" *ClinRehabil* 1999. 13:373

[16] Lance JW. Symposium synopsis. In: Feldman RG, Young RR, Koella WP, eds.*Spasticity: disordered motor control*. Chicago: Medical Publishers, 1980

[17] Mark Guttman, Stephen J. Kish, Yoshiaki Furukawa. Current concepts in the diagnosis and managementof Parkinson’s disease. *Canadian Medical Assoc. Journal* Feb. 4, 2003; 168 (3)