A Review of Upper Limb Rehabilitation Robot

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Abstract

Stroke is a leading cause of upper limb disability, which can affect numerous daily activities that require reaching and manipulation movements. Stroke patient needs to undergo a rehabilitation process under the supervision of physiotherapists. Unfortunately, due to the limited availability of therapists, these processes also may be limited and required the assistance of robotic devices for a rehabilitation program. However, although researchers in the field of robotic rehabilitation have designed and developed numerous robotic devices, it still needs improvement in term of design complexity. This paper aims to review the design of upper limb rehabilitation robot for reaching and manipulation movements. The main issue to address and the proposed solution are also discussed in this paper to improve the robot design as efficient as existing complex robotic devices.

Keywords: Stroke, upper limb, rehabilitation, robot.

1. Introduction

Stroke is classified as a circulatory system disease. Normally stroke will remain for the long term and to recover from a stroke; patients need motivation and a strong mentality. In order to support the recovery process, a suitable rehabilitation facility is required. In the stroke rehabilitation process, the appropriate treatment will be given to the stroke patients according to their own capabilities. Generally, there are two types of stroke treatment, which are Physiotherapy (PT) and Occupational therapy (OT) [1]. Furthermore, robotic rehabilitation is divided into two types of rehabilitator tools which are training and assessment tools. Training rehabilitator tools focused on the motorised design while assessment rehabilitator tools focused on non-motorized design. The use of a rehabilitation robot for physical rehabilitation of the upper limb following a brain injury can assist physiotherapists in rehabilitation program [2].

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2. Upper Limb Rehabilitation Robot

Upper limb rehabilitation robot usually has been designed using end-effector-based systems or exoskeleton-based systems [3]. Exoskeleton-based system robot has many numbers of Degree of Freedom (DOF) that allow this robot to make a lot of movement because it has a more point connection axes [4]. End-effector based system robot can be categorized as a simple operation robot and it is easy to operate compared to the exoskeleton-based rehabilitation robot [5]. Besides, the end-effector based rehabilitation robot can be divided into three categories which are a robot for manipulation, robot for reaching, and robot for manipulating and reaching.

2.1 Robots for Manipulation

A study to ascertain the needs of chronic stroke patients with a slightly defective hand function indicates that knob manipulation (e.g. rotate the doorknobs), playing cards, handwriting, driving, and actions that may require bimanual manipulation (e.g. buttoning a shirt) are the most desirable task to recover [6]. There are several rehabilitation robots that perform hand manipulation training which is Hand-Wrist Assisting Robotic Device (HWARD) [7] and Wrist-RoboHab [8]. Figure 1 shows the robotic devices used for hand manipulation.

(a) (b)

Figure 1: Manipulation rehabilitation robots. (a) HWARD [7], (b) Wrist-RoboHab [8]

Takahashi et.al [7] has developed Hand-Wrist Assisting Robotic Device namely HWARD robot. HWARD provides the combination of hand grasping with wrist extension of joint movement to increase the grasping point force. Furthermore, HWARD allows the wrist, fingers, and thumb to perform the rotational movement based on the 3 DOF design mechanism [7]. Some researcher focusses more on wrist treatment for upper limb stroke patients. Baniasad et.al. [8] has developed a robot namely Wrist-RoboHab. Wrist-RoboHab is based on a 1 DOF system designed for passive exercises of the upper limb. This robot provides assistance for forearm pronation/supination and flexion/extension of the wrist [8]. Furthermore, Wrist-

RoboHab system consists of two actuator sensor units which assign for both impairment and non-impairment hand, and it is fixed on a table using the concept of two linear guides [8].

2.2 Robots for Reaching

Practically, reaching motion can be categorized as the most meaningful functions and it is essential for daily activities i.e. drinking and eating. Abdul Rahman, H et.al [9] has done some study to investigate the minimal requirements of a rehabilitation robot that will be used to train upward arm reaching movement. The result shows that concave, linear and convex trajectories were formed during reaching movement in upward directions, and the curvature in these trajectories depended on the level of the target distance [9]. MIT-Manus [10] and Mechatronic System for Motor Recovery after Stroke (MEMOS) [11] are examples of the rehabilitation robot for an upper limb that allows training of reaching as shown in Figure 2. Clinical trials with these devices proving the effectiveness of the robot in neurorehabilitation [12].

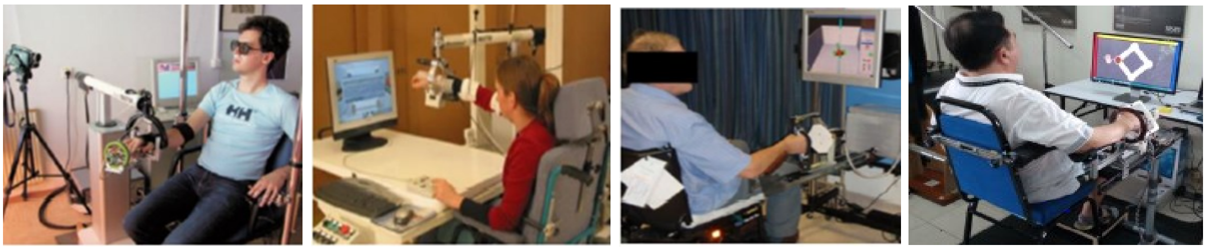
(a) (b)

Figure 2: Reaching rehabilitation robots. (a) MIT-Manus [10], (b) MEMOS [11]

MIT-Manus is a rehabilitation robot designed for neurological application [10]. MIT-Manus is a 2 DOF robot that provides assistance to train and guide patient's for reaching movement and it also can record the velocity, position, and force applied by the patients. The design of this device used the concept of a planar module in order to train stroke patients to perform their reaching movement [10]. Micera et.al. [11] had designed a simple robotic system for neurorehabilitation called MEMOS. MEMOS is a planar robot with 2 DOF in a cartesian configuration and the work plane for this robot is in a rectangular shape in order to allow the movement of stroke patients during the rehabilitation process [11]. Linear guide rails concept has been adopted perpendicular into the design to perform the reaching movement.

2.3 Robots for Reaching and Manipulation

Isolated reaching or hand manipulation training may not transfer well to ADL [13]. Thus, it is important to develop a system that includes both reaching and hand manipulation movements together. For example, HEnRiE [14] and Gentle/G [15] used Haptic Master [16] as the main interface to train both reaching and grasping in a reach-grasp-transfer release sequence. However, a large number of DOF needs to control the movements in space for this type of system. Figure 3 shows the dedicated robot which are HEnRiE [14], Gentle/G [15], ReachMAN [17] and iRest [19].



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

Figure 3: Reaching and manipulation robots, (a) HEnRiE [14], (b)Gentle/G [15], (c) ReachMAN [17], (d) iRest [19]

Mihelj et. al. [14] has designed a Haptic Environment for Reaching and Grasping Exercise (HenRiE). It consists of a robot with three active and two passive degrees of freedom and a grasping device with one degree of freedom [14]. The device enables measurement of forces during finger flexion and extension. Loureiro and Harwin [15] had conducted some research on the design and control of a robotic neuro-rehabilitation system. Gentle/G is the 9 DOF robotic rehabilitation devices that can perform hand reaching and hand grasping. This robot consists of 3 passive DOF (roll, pitch, and yaw) and 3 active DOF. This Gentle/G performs training in reaching, grasping, transferring, releasing in sequence. This mechanical design of this robot is more complicated compared to the other reviewed robot due to the higher number of DOF.

Three DOF compact and simple design namely ReachMAN [17] has been developed to train to reach in linear movement, forearm supination/pronation movements, and hand opening and closing movements. However, Tong Liu Zhu et al [18] state that the mechanical design for hand opening/closing and forearm pronation/supination not powerful enough for some patients. Therefore, ReachMAN2 has been developed to overcome ReachMAN drawbacks.

Nevertheless, the design of ReachMAN2 is more complex compared to ReachMAN. Abdul Rahman, H et.al [19] has designed an interactive rehabilitation and assessment tool namely as iRest. The iRest is a three DOF robot that performs an assessment for reaching and manipulation movement. The iRest is a design without robotic actuators and become more safety compared to the robot that uses a robotic actuator. However, in term of mechanical design, the grasping mechanism for iRest require enhancement to reduce the complexity of the design and additional usability to access for hand grip function. Table 1 shows a summary of robots for upper limb rehabilitation.

Table 1: Summary of robots for upper limb rehabilitation

	Robot	DOF	Movements	Notes
Manipulation	HWARD [7]	3	• Extension/ flexion of four fingers • Thumb extension • Wrist	• Pneumatically-powered actuators
	Wrist-RoboHab [8]	1	• Forearm Pronation/supination • Wrist flexion/extension	• Different type of training can be performed by changing the orientation of the device
Reaching	MIT-Manus [10]	2	• Reaching	• Training reaching movement in horizontal planar plane
	MEMOS [11]	2	• Reaching	• Training reaching movement in horizontal planar plane • Timing belt concept has been used
Reaching and manipulation	HEnRiE [14]	5	• Reaching • Grasping	• Implemented a virtual physiotherapy during training
	Gentle/G [15]	9[3*]	• Reaching • Fingers MCP • Finger PIP • Thumb MCP	• Training in reach-grasp-transfer-release-sequence
	ReachMAN [17]	3	• Reaching • Forearm pronation/supination • Grasping	• Training three type of movement separately or in combine mode
	iRest [19]	3	• Reaching • Forearm pronation/supination • Grasping opening/closing	• Assess three types of movement separately or in combine mode
[*]: number of passive DOF if available otherwise all are active **MCP: metacarpophalangeal** **PIP: proximal interphalangeal**				

3. Main Issue and Proposed Solution

Although researchers in the field of robotic rehabilitation have designed the robotic assessment tools, it still needs improvement in term of design complexity. Generally, the more complex the mechanical design, the more expensive, less safe and less number of potential users it has.

Hand grasp mechanism is the main requirement to assess the hand grip function during the rehabilitation process. The hand grip thickness can be defined when the finger-thumb meets the end of the middle finger [18]. There are several dedicated robots design that can be a point more on its grasping mechanism design which are Hand-Wrist Assisting Robotic Device (HWARD) [7], MIT-Manus [10], and iRest [19]. However, all these dedicated robots have no grasping mechanism that can assess the hand grip force applied by the patient's hand. Therefore, the grasping mechanism should be enhanced by adding a sensor that can assess the hand grip force.

The smoothness of the movement mechanism is one of important criteria in order to assess the voluntary movement of the patient's upper limb. The grasping mechanism is the main importance mechanism of the iRest to assess forearm (pronation/ supination) and hand (opening/ closing) movement. However, it cannot assess the patient's voluntary hand (opening and closing) movement during performing hand rotation due to the gravity effect. Reaching mechanism is functioned to generate linear reaching movement. The smooth mechanical design will be resulting in high accuracy of the assessment result. The design of iRest reaching movement was based on ReachMAN [17]. However, the overall reaching mechanism is complex and heavy. Therefore, the proposed solution for designing a compact rehabilitation robot is by using a pair of a linear guide rail and a sliding bearing which has been used in MEMOS [11] design for reaching movement.

4. Conclusion

The review discusses relevant literature for upper limb rehabilitation robot. It was found that the upper limb robotic rehabilitation can help to improve the conventional assessment for a rehabilitation program. It shows that the end-effector based system robot is less complicated compared to the exoskeleton-based system robot. The hand grip mechanism of the rehabilitation device also has been discussed. The discussion focused more on the grip mechanism design in order to assess the hand grip function. Therefore, it would be beneficial if a simple, non-motorized system with few DOF can be designed to improve iRest design and assess the upper limb function that involves reaching and hand manipulation movements as efficiently as existing complex robotic devices.

Acknowledgement

The authors would like to thank the Ministry of Higher Education Malaysia (MOHE) and Universiti Tun Hussein Onn Malaysia (UTHM) for their supports under Tier 1 Research Grant Vot U866.

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