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Assistive-as-Needed Strategy for Upper-Limb Robotic Systems: *An Initial Survey*

Assistive-as-Needed Strategy for Upper-Limb Robotic Systems: *An Initial Survey*

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Abstract. Stroke is amongst the leading causes of deprivation of one's ability in carrying out activities of daily living. It has been reported from literature that, the functional recovery of stroke patients are rather poor, unless frequent rehabilitative therapy is assumed on the affected limb. Recent trends of rehabilitation therapy have also shifted towards allowing more participation of the patient in the therapy session rather than simple passive treatments as it has been demonstrated to be non-trivial in promoting neural plasticity to expedite motor recovery process. Therefore, the employment of rehabilitation robotics is seen as a means of mitigating the limitations of conventional rehabilitation therapy. It enables unique methods for promoting patient engagement by providing patients assistance only as needed basis. This paper attempts on reviewing assist-as-needed control strategy applied on upper-limb robotic rehabilitation devices.

1. Introduction

The life expectancy of the elderly, over the past two decades, particularly those of the age of 60 years and above has increased significantly [1]. The Malaysian Ministry of Health's annual report in 2011 conveyed that the Malaysian population between the age group of 0 to 18 years old records both physical and cerebral palsy disabilities at around 11% and 7%, respectively [2]. In addition, the report also highlighted that there was an increase of stroke patients on an annual basis approximately 300% annually. These statistics reflect the size of the segments in the society that are diagnosed with disabilities that in turn depriving them of performing activities of daily living (ADL) [3].

Rehabilitation is a process by which patients undergo treatment to aid them in regaining and relearning the existing motor skills for ADL [4]. The period of stroke rehabilitation spans very broadly, as the rehabilitation therapy may transpire as soon as in the sub-acute stage (immediately after the incident of stroke) and can reach out into the chronic stage too (six months post stroke) [5]. Direct involvement is predicted to be sufficient on the condition of recovery. Emphasis is often given towards gait rehabilitation whilst the upper extremity is usually overlooked during the initial stages although there is a greater chance for recovery. Therefore, stroke patients often do not reach the maximum ability for recovery in their upper extremity when discharged from inpatient settings [6].

The involvement of robotic devices to grant rehabilitation therapy is a comparatively recent area within the field of robotics in healthcare and arise from the concept of adopting robots to support people with impairments. In turn out, this has contributed to the increase in a myriad of robotic rehabilitation devices. As the rehabilitation device is under the therapist's supervision, the main requirement in the field of robotics rehabilitation is primarily on how therapist's expert knowledge and skills can be embedded into the robotic system with the growing technologies. The system in envisioned to not only being able to provide more assistance but also offer other observations into the efficacy of the treatment.

Rehabilitation robots essentially operate close to the human user, and it should be able to deal with various human joints individually and concurrently imitate human motion. This calls for a robot design that is ergonomic, reliable and user-friendly. Interaction forces between the human user and the robot should also be taken into consideration in controlling the robot in addition to its position. The robot is required to not only be able to carry the user's limb but moreover is able to react to the forces applied by the user's limb as well. Moreover, modulation of the system is desirable as it is able to provide for modifications of the rehabilitation treatment that fits the patient's progress. These conditions bring in some challenges in the control of robots for rehabilitation which are described as follows; 1). Position control: Position control for robots includes either the joint based or space based trajectory tracking that moves as fast as possible or with a uniform velocity. In contrast, the actions of a rehabilitation robot should be smoother and have a velocity profile similar to that of normal human action. 2. Adaptive force control: The robot requires to be able of interacting and reacting to movement caused by the user in real-time. Various kinds of rehabilitation activities will need specific kinds of interaction. Furthermore, modifications to the difficulty or amount of assistance required during therapies should also be made available to provide users with various stages of impairment.

This paper is trying to embark in benchmarking the existing techniques in assist-as-needed strategy for upper limb rehabilitation robot system. The development of the robotic devices is described in section 2.1. Then section 2.2 summarizes the findings from other works that use different assist-as-needed control strategy for the upper-limb robotic rehabilitation.

2. Literature Review

The existing proposed approaches are briefly presented and reported which constitute the dealing with the upper-limb rehabilitation. The existing proposed approaches that are reviewed in this paper covers features that appear significant in control of the upper-limb robotic system.

2.1. Development of Robotic Devices for Upper-Limb Stroke Rehabilitation

Assistive robotics to support people with disabilities including rehabilitation has been an extensive research area for the last few decades to support, strengthen and quantify rehabilitation process. This kind of robot provides autonomous training where patients are involved in the repeated exercise of goal-directed tasks leading to improvements in motor function. It appears that with respect to upper-limb rehabilitation, the earlier versions of robotic manipulators have been used to move the patient's impaired hand and arm to desired position in a 3-D plane enabling the rehabilitation of the elbow and shoulder joints. Controller designs are then incorporated to ensure the safety of such rehabilitative systems to the users by allowing regulated interaction forces [7]. It has been reported that early clinical trials demonstrated that such rehabilitation devices were safe for human use and to augment traditional mode of therapy [8].

Later devices aimed to expand the capabilities of robotic therapeutic devices by targeting the more on the distal segments of the upper-limb, with wrist and hand modules to attach to previously developed arm devices [9], standalone wrist and/or hand devices [10] and also shoulder and elbow devices [11]. Many of these are exoskeleton type devices, which aim to isolate the motion of individual joints. Many of these devices isolate the motion with respect to individual joints and have a limited range of motion (ROM) in comparison with endpoint manipulators. Nonetheless, it is worth to mention that, it rehabilitates the targeted joint(s) efficiently and allow reasonably accurate data collection on the patient's limb motion.

2.2. Assist-as-Needed (AAN) Control Strategy

The main purpose of robotics based rehabilitation is to assist patients to undergo rehabilitation in addition to reduce the dependency on the therapists. However, to complete the prescribed exercise regime demands significant effort from the patient. Therefore, the strategy of assist-as-needed is paramount so as to contribute the minimal amount of robot assistance to aid the patients in rehabilitation. There are various methods that have been developed by researchers and the most basic type of controllers found from the literature and often applied in robotic rehabilitation is impedance controller [12]. The objective of deploying impedance controller is to ensure the impaired upper-limb to move on a specific path during the therapy sessions. The notion behind the aforementioned controller is to compare the kinematics of the robot which is the position and velocity of the desired reference trajectory and to apply force proportional to a weighted sum of the position and velocity errors [13]. Impedance controller is well suited to the robot device for stroke rehabilitation, where the restoring force which is proportional to the perpendicular distance from the path is provided by the robot in the event the patient's hand deviates from the prescribed path [14]. Nonetheless, if the prescribed motion is successfully carried out by the patient, the robot does not apply any force. Another type of controllers requires the determination of both the desired path and the time required for completion. In such a case, the desired trajectory can be defined as minimum jerk trajectory (a specific trajectory which is smooth, and has bell-shaped velocity profile that minimizes the change in acceleration during movement) [15] or an average trajectory that has been pre-recorded from healthy subjects. Based on this definition, then the robot provides an assistive force proportional to the distance the subject’s arm that lags the desired trajectory [16]. Although the implementation of this controller is recommended for certain trajectory between the starting point and the target point, there is another study conducted by introducing alternative approach where patients have the option to select the trajectory by their own, while the controller still supports the motion to reach the target [17]. Feasibility study of these systems has been carried out on stroke patients [16]-[18], and it was shown that these algorithms result in a reduction in muscle tone [7], significant functional improvements [19], and better functional improvements than robotic therapy designed to mimic the intensity of traditional therapy [20].

Although this controller has shown positive results in clinical trials, nevertheless, its tendency or "slacking" for the patient to rely heavily on the assistance force have been recorded [21]. In order to compensate this tendency, several studies have been conducted by incorporating the forgetting element in the controller. The goal behind the idea stemmed to reduce the amount of assistance to the patients after each trial if it was successfully implemented, thus further promote more active participation from patients [14], [22], [23]. This type of controllers requires the knowledge of both the estimated inertia and damping of the robotic system as well as the patient's arm in order to compensate the forces arises from these properties. Due to unknowns in the explicit model, researchers have also made an effort to model the patient’s effort contribution at various points in the workspace. The contribution of patient’s effort is modeled by using radial basis function (RBF) and this estimated function is updated during training [24]. There are also studies on using Bayesian learning techniques to measure the appropriate amount of assistance required to accomplish the task [25]. Pérez-Rodríguez et al. [22], investigated on the path deviations from the desired trajectory that could be anticipated by modelling the patient’s ability. The implications of this anticipation lead to the introduction of corrective force that can be applied in prior to the deviations, thus the force supplied by the robot is reduced. In another study, Wolbrecht et al. made a comparison between their adaptive controller with and without a forgetting term in clinical trials on both stroke and healthy subjects [14]. The output obtained from the study indicated that the forgetting term leads to a more active involvement of the patient in the therapeutic process. Following the positive results of this study, a variety of improvements in the modelling of patient’s effort such as the directionality of movement were demonstrated. Nonetheless, the ability of the controller is only conducted on subject healthy alone [26]. In order to overcome the problem, a study on the dependency of velocity in the model investigated applied to the stroke patients [26].

Another potential opportunity is to modify the difficulty of the movement task adaptively. In the study, the subjects were asked to track the moving targets in a sinusoidal pattern with the movement of the wrist and the increase of required range of motion after each attempt if successful [27]. In this study, three stroke subjects have been selected and tested and the preliminary results showed the potential of the method to improve a variety of subject's wrist movement. A follow-up study was carried out by [28] where eleven stroke subjects were chosen, and the results showed the improvements in the subjects' active ROM and measurable improvements in motor function. In addition, a different method has been adapted to match the difficulty of the task as being carried out by [29]. In this research, the authors employed machine learning techniques to classify the physiological state of the subject as "relaxed", "medium stressed", or "over-stressed" based on physiological signals (heart rate, respiratory rate, skin temperature, and galvanic skin response) and adjusted the difficulty level of the tasks accordingly. The experimental results suggest the feasibility of the proposed method, nonetheless, it is worth to note that clinical trials on stroke patients has yet been investigated. Table 1 summarizes the literature survey conducted on the topic.

Table 1. Assist-as-needed (AAN) strategies for upper-limb stroke rehabilitation robotic.

Author	Robotic System	Strategies
Pehlivan et al. (2016)	3-DoF wrist exoskeleton	Employ Kalman Filter and Lyapunov method to estimate the patient capability based on joint position and velocity. The assistance is provided to the patient if the patient is unable to perform the motion (position & velocity) while the assistance is decreased if the patient achieves the prescribed motion
Pérez-Rodríguez et al. (2014)	Simulated 8-DoF arm orthosis	A dysfunctional-adapted biomechanical prediction subsystem is developed to provide an anticipatory force-feedback to patient in order to avoid the trajectory deviations. The assistance force is decrease when patient is success to complete the task.
Squeri et al. (2011)	3-Dof wrist exoskeleton	Impedance control scheme is used to generate an assistive force field based on relative positions of the target and the end effector. The assistance is provided based on the error (trajectory tracking) produced by the patient.
Bower et al. (2013)	2-finger grasp robot	State dependence (position and direction) and inertial force are used as input to AAN strategy. The RBF activation function is applied

		to model the effort from patient. The AAN strategy will decrease the assistance to the patient in the event that the patient is able to complete the task by themselves.
Guidali et al. (2011)	7-dof arm exoskeleton	The kinematic error (velocity and time) is used as an input to AAN strategy. The assistance strategy is decrease when the patient is able to achieve desired task.

3. Conclusion

It is apparent from the literature that the assist-as-needed methods encourage active patient participation in movement therapy by providing a bare minimum necessary assistance. Under the assist-as-needed strategy, the robot is no longer needed to contribute full support throughout the path of motion trajectory; whereas the robot can impel subjects to use their muscular strengths while trying to keep up with the predefined motion trajectory. It has also been demonstrated from clinical trials the feasibility of the methods as well as the functional improvements as a consequence of this form of training. However, controlled clinical trials are still needed to compare training methods and quantify possible benefits of such strategy over traditional therapy.

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