# Robotic Devices and Proprioception

Duygun Erol Barkana¹ and Sule Badilli Demirbas²

¹Department of Electrical and Electronics Engineering, Faculty of Engineering and Architecture, Yeditepe University, Istanbul, Turkey
²Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Yeditepe University, Istanbul, Turkey

*Corresponding author: Sule Badilli Demirbas, Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Yeditepe University, Istanbul, Turkey, Tel: 90-216-5780000/ (2741-3289); E-mail: b_sule@hotmail.com

## Abstract

In Recent years robotic rehabilitation has become an import issue on rehabilitation procedures. Robotic devices are used for both assessment and treatment. This chapter presents importance of assessment and treatment of proprioception and robotic devices that have been developed to assess proprioception in patients in four sections. Section one presents the effect of loss of proprioception in rehabilitation programs. Technological advances (robotic devices) are presented in section two. Section three provides details of the robotic devices that are used to assess the proprioception. Section four discusses the robotic devices that are used to treat the proprioception.

**Keywords:** Assessment, Proprioception, Robot-Assisted Rehabilitation System, Treatment

## Proprioception and its Role in Rehabilitation Programs

Proprioception is defined as the perception of position, motion and force generated by the body based on sensory information such as muscle spindles, joint receptors. Proprioception is usually evaluated via joint position sense and kinesthesia. Joint position sense measures the ability of the patient to reproduce a predetermined angle in the range of motion, whereas kinesthesia determines the threshold to detect the passive motion of the patient. People use sensory feedback such as proprioception to control their arm and hand motion during the execution of the activities of daily living tasks.

Loss of proprioception may affect rehabilitation program, and may be the reason of the failure of the patient’s response to the rehabilitation treatment. Proprioceptive deficits have been shown to negatively impact safety, postural stability and motor function [1]. Impaired proprioception has been shown to have prognostic significance in self-care and length of hospital stay [2-5]. Some reports have indicated that position sense, a sub-component of proprioception, strongly correlates with motor recovery of the hemiplegic arm [6-12]. Thus, it is important to assess and treat the proprioception deficiencies for the success of the rehabilitation therapy.
Technological Advances in Assessment and Enhancement of the Proprioception

Recent technological advances have given the clinician the potential to assess and treat the proprioception deficiencies. Robotic devices, which are currently in use in rehabilitation, have also been developed to assess proprioception in patients with musculoskeletal injuries, to investigate if position sense is dependent on deficits in motor performance [4,13-17]. The reliability of the robotic devices for position sense assessment has shown to be better than standard clinical assessment tools [18-21]. Note also that robotic devices have shown to be helpful in neuromotor rehabilitation because it is possible to deliver interactive and repeatable sensorimotor exercise and monitor the actual performance continuously using these devices. Although the cost of purchasing and developing these robotic devices for both assessment and treatment is expensive relative to the current clinical methods, the robotic technology can provide distinct cost savings in the long term.

Assessment of Proprioception Using Robotic Devices

Proprioception includes two components, the sense of stationary position of the limbs (limb position sense), and the sense of limb movement (kinaesthesia). The position sense and kinaesthesia can be clinically evaluated individually to get information about specific cutaneous sensory receptors, peripheral nerves, dorsal roots and central nervous system pathways [22]. Various studies are conducted to assess the proprioception. Histologic studies are conducted to identify mechanoreceptors within the specific joint structures. Neurophysiological testing is used to measure sensory threshold and nerve conduction velocities. Clinically, proprioception can be assessed by measuring the two components that make up the proprioceptive mechanism namely kinesthesia and joint position sense [23]. In contrast to traditional assessments of physical well-being, which have focused largely on the ability of individuals to generate motor output, a greater emphasis is now being placed on sensory feedback acuity.

Various exoskeleton and end-effector based robotic devices have been developed for upper-limb motor assessment and sensory assessment. Robotic devices have also been used to quantify features of the motor system such as strength, muscle stretch reflexes, spasticity/tone, range of motion and basic motor coordination [24-31]. In recent years, robotic devices have also been developed to quantify impairments in proprioceptive function for individuals with neuromuscular disorders.

A bilateral exoskeleton robot called KINARM (BKIN Technologies Ltd., Kingston, Ontario) has been developed to measure proprioceptive function (figuring out where the body part is in space) following stroke [32,33]. KINARM is capable of testing planar upper limb movements in an augmented reality environment. KINARM permits arm movements in the horizontal plane, monitors shoulder and elbow motion, and can apply mechanical loads at the shoulder and/or elbow. It has been shown that the KINARM robot can measure the position sense with less chance of error and can provide a reliable quantitative means to assess deficits in limb position sense following stroke [28].

Another robotic device has been developed to document proprioceptive deficits in the upper limbs of patients with stroke [34]. A robotic manipulandum has been used to produce arm displacements (of differing magnitudes) to stimulate proprioception in stroke survivors with deficits in upper extremity function, and in neurologically intact individuals [17].

RehabRoby has also been designed to assess the proprioception, and motor deficits of patients with musculoskeletal injuries. RehabRoby has been used to assess the amount
of proprioceptive deficiencies by comparing with the intact side and to understand matching error at the target activity. RehabRoby is a robotic device that is designed to provide extension, flexion, abduction, adduction, rotation, pronation and supination upper-extremity movements, and also combination of these movements for activities of daily living. Additionally RehabRoby can be easily adjustable for people with different arm lengths. The design details of RehabRoby can be found in [35]. A control architecture has also been developed for RehabRoby to take into account therapist decisions, to decide on the plan of action, and to provide assistance to patients to complete a rehabilitation task [35-40].

Biodex Medical Systems has developed the Biodex Stability System to identify and quantify proprioceptive deficiency. The Biodex Stability System assesses dynamic muscular control of posture on an unstable support surface, rather than assessing movement of the body’s Center of Gravity (COG) above a stationary foot. Thus, Biodex Stability System is a more sensitive test of postural stability, and could be suitable for orthopedic rehabilitation [41-44].

**Enhancement of Proprioception Using Robotic Devices**

Normal daily living activities require proper proprioceptive sense combined with proper neuromuscular activity. After injuries the lack of proprioception leads improper movement patterns. Repeated exercises have positive effects on motor recovery and also on enhancement of proprioception [45]. Repeatable exercise may increase the mechanoreceptor sensitivities, by better movement control with muscle strengthening, better visco-elastic properties of muscular tissue, enhanced oxygenation and increased body temperature [46]. Muscular exercise improves knee position sense in humans, and the plastic changes induced in the cortex because of repeated positioning of body and limb joints in specific spatial positions [47,48]. However note that vigorous exercises can also have negative effects like deterioration on joint proprioception during fatigue state, in which the metabolic products of muscular contraction directly impact the discharge pattern of muscle spindles and disrupting afferent feedback [49]. Furthermore, repetitive passive movements and tractions can cause proprioception deterioration due to ligament laxity. Some researchers hypothesize that individuals are prone to make more position-matching errors after repeatable exercises. On the other hand, the most recent studies on the effect of repetitive exercise on position sense appear to challenge this hypothesis. It has previously shown that repeated passive movement with rapid angular velocities is capable of improvement of knee proprioception, specifically in active repositioning and kinesthesia measurements [50]. Therefore, it remains controversial to explain how repetitive exercise affects limb position sense, and more research is needed to achieve an agreement.

Robotic devices can be helpful in neuromotor rehabilitation because it is possible to deliver interactive and repeatable sensorimotor exercise, and monitor the actual performance continuously using them. Additionally, robotic devices can provide controlled haptic environments in which patients can learn to move only by using proprioceptive information. Various robotic devices have been developed for treatment of motor impairment and disability in rehabilitation of neuromuscular problems [51-60]. Existing robotic device has shown to provide controlled, quantifiable, and repeatable exercise (Table 1). There are many devices developed for rehabilitation but only a few rehabilitation robotics are used for proprioception enhancement. But it is known that repetitive exercises can improve proprioception therefore these devices which leads repetitive movements are also taken in this section as robotics which can be used for proprioception enhancement.
Unfortunately not so many robotic devices have been developed that focus on the treatment of proprioceptive functions of patients. To our knowledge, only one robotic system has been developed which has shown that patients may benefit more from proprioception-enhancing therapy sessions (“without vision”) than from traditionally visually guided training [65].

Massachusetts Institute of Technology (MIT) - Manus, the pilot rehabilitation robotic system, has been developed in MIT in the early 1990’s [15,61]. It provides two dimensional movements of the patient’s hand. The end-effector of MIT-Manus is the robot-mounted handle gripped by the patient, and forces and movements can be applied to the system using this handle. A cursor on a video screen represents the position, direction and speed of the movement of the robotic arm. The position, speed and forces or torques of a patient’s complete movement are recorder during the training and therapy. The MIT-MANUS robot assists the patients by correcting the path or increasing the speed of movement to the target during the point-to-point movement. MIT Manus uses impedance controller to support the motion of the hand to the target position. The MIT-Manus is back-drivable, thus the patient operates a robotic device that moves easily even with weak forces. Force and position sensors are used to feed the impedance controller.

Mirror Image Movement Enabler (MIME) robotic device has been used for the affected limb or paired with a second robotic arm to execute mirror movements with the affected and unaffected limbs simultaneously [51,52]. Patients can achieve three dimensions activities of daily living movements during the therapy with MIME. MIME is composed of a PUMA 560, a six degrees-of-freedom industrial robot manipulator and a hand-attachment in the end-effector. The forearm of the patient can be positioned within a large range of spatial positions and orientations with this mechanism. The position values that are obtained from the intact arm are given to the effected arm using a digitizer connection. It is possible to execute passive, active and active limited therapy methods using MIME. Position and admittance control strategies are implemented with the six Degree-of-Freedom (DoF) force-torque sensor and position sensors to execute four different control modes (passive, active-assisted, active constrained and bilateral modes).

GENTLE/s is another end-effector based robot supported rehabilitation system that consists of a three DoF robot manipulator named Haptic Master and a virtual reality [60]. In GENTLE/s, the spatial position for the elbow is undetermined, thus two ropes of a weight lifting system is used to compensate the gravity effect. GENTLE/s allows patients to perform 3-dimension point-to-point movements. GENTLE/s provides assistance to the patients to move to the target points along the predefined trajectories using the admittance control.
NeReBot has been designed as a three DoF, wire-driven, end-effector based robot for upper-extremity rehabilitation [54,66,67]. There are three wires, which are connected to the patient’s upper limbs through a splint. The rehabilitation treatment based on the passive or active-assistive spatial motion of the limb is provided controlling the lengths of the wires driven by electric motors. Switching Proportional-Integral-Derivative (PID) Control has been used for the position control of NeReBot.

Mechatronic System for Motor Recovery after Stroke (MEMOS), has been designed to improve motor recovery of hemiparetic subjects by using a simple mechatronic system. MEMOS is able to provide information about the movement efficacy and accuracy during the tracking tasks. This is important because the quantitative evaluation procedure allowed by the robot measured parameters can improve the effectiveness of the rehabilitation treatment [68].

Simulation Environment for Arm Therapy (SEAT) has been developed to evaluate the principle of the ‘mirrored-image’ by the provision of a bimanual, patient controlled therapeutic exercise based on a driving simulator. The robotic device comprises a customize design of a car steering wheel equipped with sensors to measure the forces applied by a patient’s limbs, and an electrical motor to provide pre-programmed assistance and resistance torques to the wheel. Visual cues have been given to the patient via a commercially available low cost PC-based driving simulator which provides graphical road scenes [56].

COZENS has developed a one-degree of freedom robotic device for arm rehabilitation. The patient’s forearm is fixed to a lever that can rotate in the horizontal plane about an axis aligned with the elbow joint. Straps are used to fix the upper arm of the patient which allows the robotic device to act like an exoskeleton for the elbow joint. Interactive assistance is provided on the basis of position and acceleration signals measured by an electrogoniometer and an accelerometer. When a voluntary movement that is characterized by a minimum acceleration and speed is detected, then the sensor signals trigger the robot actuation. A torque controller gradually changes the amount of torque applied by the robot to avoid transforming the exercise into a pure patient-passive manipulation during the movement [57].

ARMin, which has been designed for arm therapy is an exoskeleton robot equipped with position and force sensors [58]. ARMin has four active and two passive DoF to allow elbow flexion/extension and spatial shoulder movements. Later, a second version of ARMin, called ARMin II, has been developed. The mechanical structure, actuators, and sensors of the ARMin have been optimized for the applications of impedance and admittance control for ARMin II. Three therapy modes which are passive mobilization, game therapy and task-oriented training can be applied to patients with ARMin II. In the latest work, a new ergonomic shoulder actuation principle and its implementation of ARMin II has been developed which is called ARMin III arm therapy robot. Three actuated degrees of freedom for the shoulder and one for the elbow joint are included in ARMin III. Actuated lower arm pronation/supination and wrist flexion/extension are made available with the additional module in ARMin III. Impedance and admittance control techniques have been used for the ARMin robot-assisted rehabilitation systems.

The T-WREX (Therapy Wilmington Robotic Exoskeleton) is a passive, five DoF, body powered device with no actuators exoskeleton. T-WREX has been designed to enable patients with significant arm weakness to achieve intense movement training without the expense of a physiotherapist [64]. It provides a large 3D workspace that is approximately 66% of the natural workspace of the arm in the vertical plane and 72% in the horizontal plane. Weak patients can move their effected arm easily with the support provided against
gravity. Pneu-WREX is a robotic version of T-WREX that can apply a wide range of forces to the arm during upper extremity movements using pneumatic actuators [59]. Non-linear force control and passive counter balancing techniques have been used for Pneu-Wrex.

L-Exos (Light Exoskeleton) is an exoskeleton robot with force feedback that is designed for right human arm rehabilitation [62,69]. It has five DoF, four of which are actuated and it can apply a controllable force up to 100N at the center of the patient’s hand palm. L-Exos has active and tunable arm weight compensation. The results of the clinical trials demonstrate that L-Exos can be used for robotic arm rehabilitation therapy when it is integrated with a Virtual Reality (VR) system. Impedance control has been used for L-Exos.

The Salford Rehabilitation Exoskeleton (SRE) is a gravity compensated arm rehabilitation exoskeleton robot with seven DoF [63]. Three of these degree-of-freedoms are located at the shoulder for flexion/extension, abduction/adduction and lateral/medial rotation. Two are at the elbow for flexion/extension and pronation/supination of the forearm. The other two provide flexion/extension and abduction/adduction located at the wrist. Pneumatic actuation techniques that provide accurate position and forced controlled paths, compliance and a high level of inherent safety are used in the design of the exoskeleton. Impedance control has been used for SRE.

Another robotic device is the arm trainer. The patient’s elbow joints are flexed at about 90°. Each hand grasps a handle and can be moved in one DoF. Two handle sets are available, one with a horizontal axis for forearm pronation/supination, and one with a vertical axis for wrist flexion/extension movements. The position of the device position can be changed for the selected movement. Force and position sensors are used to enable different control modes, including position and impedance control strategies [36].

References


52. Lum PS, Burgar CG, Van Der Loos M, Shor PC, Majmundar M (2005) The MIME robotic system for upper-limb neuro-rehabilitation: Results from a clinical trial in subacute stroke. 9th International Conference on Rehabilitation Robotics, Chicago, USA.


