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Mini Review

A Review on Electromechanical Methods and Devices for Neural Rehabilitation

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Abstract

To help patients suffering disabilities caused by damage to neural system, engineers have developed new methods and devices. A recently emerging technique is called Functional Electrical Stimulation which is the application of electrical charge for stimulating damaged organ nerves and recover some muscular functions. In this paper, we aim to review the most recent developments in neural prostheses and their structures which have been designed and built to apply this technique to patients' nervous system.

Introduction

The nervous system of most quadrupeds consists of two main systems: The Central Nervous System including brain and spinal cord and the Peripheral Nervous System which is a large nervous system running through the body, controlling all voluntary and automatic body movements [1,2]. Disease like peripheral neuropathy [3], damage in spinal cord [4] and severe stroke to head can cause numbness, weakness, trouble with grasping items, problems with walking and balancing or severe debilitating disabilities. Some of these diseases and symptoms can be treated by medicines, physical therapies and surgery; however, in many cases, patients face permanent disabilities specially with those diseases related to brain and spinal cord injuries since these organs include a complex system of nerves and regeneration of those nerve cells after injury is impossible. To help patients with these sort of disabilities, engineers have proposed several electromechanical systems and methods such as designing and building neural prostheses to help patients restore some lost organs functions. In this article, we review recent developments of neural prostheses and their structures.

Neural Prostheses

Neural prostheses are a series of assistive devices which are designed and used for therapeutic electrical stimulation, reduce pain and even substitution of sensory or motor functions lost through damages caused by injury or a disease to the neural system to restore or rehabilitate normal bodily functions [5-9]. Many of these devices use a technique called functional electrical stimulation (FES) to stimulate peripheral nerves electrically using skin or implanted electrodes [10-15]. Although skin electrodes are safer and easier for patient to apply on body, a large current is needed for stimulation of nerves. Implanted electrodes can be planted at proximity of target nerve to use smaller current for stimulation. These electrodes are more complex than ordinary surface electrodes and must be clinically safe and durable [16].

Although design, construction and use of neural prostheses with implantable electrodes and stimulators are complex, in recent years, using them in patients' bodies for various purposes have been grown. To produce these stimulators, technologies like construction of pacemakers may be used so that these devices can be remain in body for years and agitate target tissues nerves using electrical stimulations [16]. Example of these kinds of neural prostheses are dorsal column stimulator [17] and deep-brain stimulators [18-20] for release pain and reduce spasticity, phrenic nerve stimulator for respiration [21,22], sacral root stimulators for bladder control [23,24] and peroneal nerve stimulator for counteracting hemiplegic foot drop [25,26].

Neural Prostheses Structures

Over recent decades, progresses have been achieved for rehabilitations and physical movements in paresis or paralyzed patients using FES technique [27]. Various optimized cycling mechanisms, stimulation strategy and stimulation patterns have been studied to rehabilitate lower-limbs of paralytics using FES to pedal stationary cycle [28-38]. Bellman et al. [39,40] designed an experimental setup using a stationary cycle with an optical encoder and a sensor attached to the crank to measure cycling cadence and crank position, a current controlled stimulator to produce pulses to activate target muscles, a data acquisition hardware and software to analyze input data from sensors and calculate output command to be applied to muscles and finally skin electrodes to deliver current to muscles. They proposed a switched system theory and a nonlinear model of a stationary FES-cyclingsystem to improve cycling cadence and performance.

Data acquisition system

Neural prostheses inducing FES usually have a data acquisition system to receive data from sensors and analytically determine the input command to muscles. This system is part of device stimulator and usually uses a controlling strategy to actively control the stimulation and induce proper charge to muscles to track the desired trajectory. For stationary FES systems, when the space limit is not crucial, usual data acquisition systems like computers or industrial or commercial stimulators like Compact RIO and Grass S8800 [41,42] can be used. For portable neural prostheses, the stimulator must be light and small and in many cases, wearable. Recently, with the advent of small and low-cost microcontroller platforms like Arduino microcontroller, wearable and carriable FES-based neural prostheses also have been designed and built [43,44]. Melo et al. [43] used Arduino MCU as their analytical modulus to develop a gait neuro-prosthesis. In their system, data received from Inertial measurement units and force sensitive resistors is analyzed and muscle stimulation command fordrop foot correction is sent to an actuation modulus of the system.

Sensors

Sensors functionality in neural prostheses is sometimes detecting and tracking patient gait events and send the data for further analyses to device data acquisition system. For example, force sensing resistors are used under the shoe or sole to detect the time when foot heel touches the ground [45-47] or gyroscopes and accelerometers to measure velocities and accelerations of different patient's body parts to detect feet gait events such as initial contact, foot-flat start, toe-off and heel-off [48-57]. Maqbool et al. [58] used an inertial measurement unit (IMU) attached to the shank of amputees for detecting patient's gait event at real time. The IMU could measure the angular velocity and linear acceleration of the shank and these data was used by data acquisition system to detect gait with accuracy of 99.78% using a special algorithm.

Neural Prostheses Applications in Animals

Neural and spinal cord damages and diseases are also common in animals and can cause effects and symptoms like in humans. Dachshund, for instant, is a kind of dog which highly susceptible to spinal cord injuries because of its special physical body. This dog is famous for its short legs in comparison with its long body which makes dog more prone to breaks and damages to back of dog where the spinal cord located. If damages to spinal cord occurs, dog may lose its sense and movement abilities in its back leg. Sometimes dog loses its walking ability completely, however, in many cases, dog automatically moves its legs and even walk because of reflexes in muscles when dog toes touch the ground. Even in such cases, dog frequently falls since it has no sense in back muscles and ligaments and cannot control its body or balance its hip.

Rehabilitation treatments of these injuries in dogs is a challenge for Veterinarians. Taghavi et al. [59,60], invented a "balancing device" to correct the gait of these patient dogs. This device included an Arduino Uno microcontroller for gathering data from an IMU and functions as a stimulator to apply voltage to target muscles. The IMU attached on the hip of dog sends data about the hip balancing status by measuring angular velocities and accelerations. The amount of voltage and the duration of stimulation is based on different algorithm and strategies that are programmed and uploaded to microcontroller. These strategies were developed based on dog anatomy and gait analyses.

Conclusion

In this paper, we reviewed newly developed neural prostheses which deliver functional electrical stimulation to damaged nerves. We showed these devices include data acquisition systems and sensors to obtain sensing data, analyze stimulation command and provide enough charge which is delivered to target nerves using electrodes. Several different processors and microprocessors as well as electrical sensors can have applications in designing and building of such devices. We explained examples that shows these devices can help both humans and animals patients.

References

1. Von Holst E (1954) Relations between the central nervous system and the peripheral organs. The British Journal of Animal Behaviour 2(3): 89-94.
2. Edwards FA, Gibb AJ, Colquhoun D (1992) ATP receptor-mediated synaptic currents in the central nervous system. Nature 359(6391): 144-147.
3. Ziegler D, Hanefeld M, Ruhnau KJ, Meissner HP, Lobisch M, et al. (1995) Treatment of symptomatic diabetic peripheral neuropathy with the anti-oxidant α-lipoic acid. Diabetologia 38(12): 1425-1433.
4. Brown TG (1914) On the nature of the fundamental activity of the nervous centres; together with an analysis of the conditioning of rhythmic activity in progression, and a theory of the evolution of function in the nervous system. J Physiol 48(1): 18-46.
5. Kraft GH, Fitts SS, Hammond MC (1992) Techniques to improve function of the arm and hand in chronic hemiplegia. Arch Phys Med Rehabil 73(3): 220-227.
6. Nudo RJ (1997) Remodeling of cortical motor representations after stroke: implications for recovery from brain damage. Mol Psychiatry 2(3): 188-191.
7. Taub E (2000) Constraint-induced movement therapy and massed practice. Stroke 31(4): 986-988.
8. Melzack R, Wall PD (1984) Acupuncture and transcutaneous electrical nerve stimulation. Postgrad Med J 60(710): 893-896.
9. Duchenne GB (1867) Physiology of Motion Demonstrated by Means of Electrical Stimulation and Clinical Observation and Applied to the Study of Paralysis and Deformities (translated from French), In: Kaplan E (Ed.), 1959 edn, BWB Saunders, Philadelphia, USA.
10. Merrill DR, Bikson M, Jefferys JG (2005) Electrical stimulation of excitable tissue: design of efficacious and safe protocols. J Neurosci Methods, 141(2): 171-198.
11. Rose TL, Robblee LS (1990) Electrical stimulation with Pt electrodes. VIII. Electrochemically safe charge injection limits with 0.2 ms pulses. IEEE Trans Biomed Eng 37(11): 1118-1120.

12. Keller T, Kuhn A (2008) Electrodes for transcutaneous (surface) electrical stimulation. Journal of automatic control, University of Belgrade 18(2): 35-45.

13. Popovic MR, Thrasher TA, Adams ME, Takes V, Zivanovic V, et al. (2006) Functional electrical therapy: retraining grasping in spinal cord injury. Spinal Cord 44(3): 143-151.

14. Mahadevappa M, Weiland JD, Yanai D, Fine I, Greenberg RJ, et al. (2005) Perceptual thresholds and electrode impedance in three retinal prosthesis subjects. IEEE Trans Neural Syst Rehabil Eng 13(2): 201-206.

15. Gan LS, Ravid E, Kowalczewski JA, Olson JL, Morhart M, et al. (2012) First permanent implant of nerve stimulation leads activated by surface electrodes, enabling hand grasp and release: the stimulus router neuroprosthesis. Neurorehabil Neural Repair 26(4): 335-343.

16. Prochazka A, Mushahwar VK, McCreery DB (2001) Neural prostheses. J Physiol 533(Pt 1): 99-109.

17. Waltz JM (1997) Spinal cord stimulation: a quarter century of development and investigation. A review of its development and effectiveness in 1,336 cases. Stereotact Funct Neurosurg 69 (1-4 Pt 2): 288-299.

18. Kumar K, Toth C, Nath RK (1997) Deep brain stimulation for intractable pain: a 15-year experience. Neurosurgery 40(1): 736-747.

19. Benabid AL, Pollak P, Gervason C, Hoffnann D, Gao DM, et al. (1991) Long-term suppression of tremor by chronic stimulation of the ventral intermediate thalamic nucleus. Lancet 337(8738): 403-406.

20. Benabid A, Koudsie A, Benazzouz A, Fraix V, Ashraf A, et al. (2000) Subthalamic stimulation for Parkinson's disease. Arch Med Res 31(3): 282-289.

21. Glenn WW, Holcomb WG, Hogan J, Matano I, GeeJ B, et al.(1973) Diaphragm pacing by radiofrequency transmission in the treatment of chronic ventilatory insufficiency. Present status. J Thorac Cardiovasc Surg 66(4): 505-520.

22. Elefteriades JA, Quin JA (1998) Diaphragm pacing. Chest Surgery Clinics of North America 8: 331-357.

23. BradleyWE, Chou SN, French LA (1963) Further experience with radio transmitter receiver unit for the neurogenic bladder. Neurosurgery 20: 953-960.

24. Stenberg CC, Burnett WH, BuntsRC (1967) Electrical stimulation of human neurogenic bladders: experience with four patients. Journal of Urology 97(1): 79-84.

25. Jeglic A, Vanken E, Benedik M (1970) Implantable muscle/nerve stimulator as part of an electronic brace. 3rd International Symposium on External Control of Human Extremities, Yugoslav Committee for Electronics and Automation, Nauka, Belgrade, pp. 593-603.

26. Waters RL, McNeaL, D, Perry J (1975) Experimental correction of footdrop by electrical stimulation of the peroneal nerve. J Bone Joint Surg Am 57(8): 1047-1054.

27. CA Phillips, JS Petrofsky, DM Hendershot, D Stafford (1984) Functional electrical exercise: A comprehensive approach for physical conditioning of the spinal cord injured patient.Orthopedics, 7(7): 1112-1123.

28. J Szecsi, P Krause, S Krafczyk, T Brandt, A Straube(2007) Functional output improvement in FES cycling by means of forced smooth pedalling. Med Sci Sports Exerc 39(5): 764-780.

29. BSKK Ibrahim, SC Gharooni, MO Tokhi, R Massoud (2008) Energy-efficient FES cycling with quadriceps stimulation. Proc13th Ann Conf of the Int Funct Electrical Stimulation Soc, Freiburg, Germany.

30. M Gföhler and P Lugner (2000) Cycling by means of functional electrical stimulation. IEEE Trans RehabilEng8(2): 233-243, 2000.

31. ES Idsø, T Johansen, K J Hunt (2004) Finding the metabolically optimal stimulation pattern for FES-cycling. Proc 9th Ann Conf of the Int Funct Electrical Stimulation Soc, Bournemouth, UK.

32. RD Trumbower, PD Faghri(2004) Improving pedal power during semireclined leg cycling. IEEE Eng Med Biol23(2): 62-71.

33. KJ Hunt, C Ferrario, S Grant, B Stone, AN McLean, MH Fraser, DB Allan (2006) Comparison of stimulation patterns for FES-cycling using measures of oxygen cost and stimulation cost. Med Eng Phys28(7): 710-718.

34. NA Hakansson, ML Hull (2009) Muscle stimulation waveform timing patterns for upper and lower leg muscle groups to increase muscular endurance in functional electrical stimulation pedaling using a forward dynamic model. IEEE Trans Biomed Eng56(9): 2263-2270.

35. TA Perkins, NN Donaldson, NAC Hatcher, ID Swain, DE (2002) WoodControl of leg-powered paraplegic cycling using stimulation of the lumbro-sacral anterior spinal nerve roots IEEE Trans Neur Sys and Rehab Eng10(3): 158-164.

36. PC Eser, N Donaldson, H Knecht, E Stussi (2003) Influence of different stimulation frequencies on power output and fatigue during FES-cycling in recently injured SCI people. IEEE Trans Neur Sys and Rehab Eng11(3): 236-240.

37. M Decker, L Griffin, L Abraham, L Brandt (2010) Alternating stimulation of synergistic muscles during functional electrical stimulation cycling improves endurance in persons with spinal cord injury. J ElectromyogrKinesiol20(6): 1163 - 1169.

38. NA Hakansson, ML Hull (2012) Can the efficacy of eletrically stimulated pedaling using a commercially available ergometer be improved by minimizing the muscle stress-time integral?" Muscle Nerve 45(3): 393-402.

39. Bellman MJ, Cheng TH, Downey, RJ, Dixon WE (2014) Stationary cycling induced by switched functional electrical stimulation control. American Control Conference pp. 4802-4809.

40. Bellman M, Cheng TH, Downey R, Hass C, Dixon W (2016) Switched Control of Cadence During Stationary Cycling Induced by Functional Electrical Stimulation. IEEE Trans Neural SystRehabilEng24(12):1373-1383.

41. Bellman M, Cheng TH, Downey R, Hass C, Dixon W (2016) Switched control of cadence during stationary cycling induced by functional electrical stimulation. IEEE Trans Neural Syst Rehabil Eng 24(12): 1373-1383.

42. Kesar TM, Perumal R, Reisman DS, et al. (2009) Functional electrical stimulation of ankle plantar flexor and dorsi flexor muscles: effects on post stroke gait. Stroke 40(12): 3821-3827.

43. Kesar TM, Reisman DS, Perumal R, et al. (2011) Combined effects of fast treadmill walking and functional electrical stimulation on post-stroke gait. Gait Posture 33(2): 309-313.

44. Luzio DM, P, Silva P, Martins J, Newman D (2015) A Microcontroller Platform for the Rapid Prototyping of Functional Electrical Stimulation-Based Gait Neuro prostheses. Artificial Organs 39(5): E56-E66.

45. Taghavi N, Luecke GR, Jeffery ND (2016) A bionic test-bed for sensing and balance augmentation in biological applications. ASME. ASME 2016 International Mechanical Engineering Congress and Exposition 4A: 11-17.

46. Lyons GM, R TS, Burridge JH, Wilcox DJ (2002) A review of portable FES-based neural orthosis for the correction of drop foot. IEEE Transactions on Neural Systems and Rehabilitation Engineering 10(4): 260-279.

47. Strojnik P, Kralj A, Ursic I (1979) Programmed six-channel electrical stimulator for complex stimulation of leg muscles during walking. IEEE Trans Biomed Eng 26(2): 112-116.

48. Rueterbories J, Spaich EG, Larsen B, Andersen OK (2010) Methods for gait event detection and analysis in ambulatory systems. Medical Engineering & Physics 32(6): 545-552.

49. Tong K, Granat MH (1999) A practical gait analysis system using gyroscopes. Med Eng Phys 21(2): 87-94.

50. Aminian K, Rezakhanlou K, De Andres E, Fritsch C, Leyvraz PF et al. (1999) Temporal feature estimation during walking using miniature accelerometers: An analysis of gait improvement after hip arthroplasty. Med Biol Eng Comput 37(6): 686-691.

51. Catalfamo P, Ghoussayni S, Ewins D (2010) Gait event detection on level ground and incline walking using a rate gyroscope. Sensors 10(6): 5683-5702.

52. Muller P, Steel T, Schauer T (2015) Experimental Evaluation of a Novel Inertial Sensor Based Realtime Gait Phase Detection Algorithm, in Proceedings of the Technically Assisted Rehabilitation Conference.

53. Aminian K, Najafi B, Büla C, Leyvraz PF, Robert P (2002) Spatio-temporal parameters of gait measured by an ambulatory system using miniature gyroscopes. Journal of Biomechanics 35(5): 689-699.

54. Gouwanda D, Gopalai AA, robust A (2015) Real-time gait event detection using wireless gyroscope and its application on normal and altered gaits. Medical Engineering & Physics 37(2): 219-225.

55. Maqbool H, Husman M, Awad M, Abouhossein A, Dehghani S (2015) Real-time gait event detection for transfemoral amputees during ramp ascending and descending, in engineering in medicine and biology society (EMBC), 2015 37th annual international conference of the IEEE, pp. 4785-4788.

56. Lee JK, Park EJ (2011) Quasi real-time gait event detection using shank-attached gyroscopes. Med Biol Eng Comput 49(6): 707-712.

57. Mariani B, Rouhani H, Crevoisier X, Aminian K (2013) Quantitative estimation of foot-flat and stance phase of gait using foot-worn inertial sensors. Gait Posture 37(2): 229-234.

58. Maqbool HF, Husman MA, Awad M, Abouhossein A, et al. (2016) Real-time gait event detection for lower limb amputees using a single wearable sensor. In engineering in medicine and biology society (EMBC), 2016 IEEE 38th Annual International Conference of the IEEE, pp. 5067-5070.

59. Taghavi N, Luecke GR, Jeffery N (2016) A bionic test-bed for sensing and balance augmentation in biological applications. ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE).

60. Taghavi N, Luecke GR, Jeffery N (2018) A wearable body controlling device for application of functional electrical stimulation. Sensors 18(4): 1251.

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