Johansson, Rolf; **Magnusson, Måns**

Optimal coordination and control of posture and locomotion. (English) Zbl 0738.73063

Math. Biosci. 103, No. 2, 203-244 (1991).

An algorithm capable for the coordination and control of functional neuromuscular stimulation as well as of protheses is presented. The rigid body mechanics of musculoskeletial motion is formulated according to Lagrange's equations. The coordination of the muscular forces is considered at the level of joint torque. The optimal control problem discussed by the authors is to minimize errors in the applied torques and the energy consumption. This problem is solved by means of the Hamilton- Jacobi equation, where explicit solutions are obtained. Stability is investigated with the Lyapunov function theory, showing that global asymptotic stability holds. An anthromorphic five-link model climbing a step is treated as illustrative example. The problem of parameter identification of the model from experimental data is considered in a special section.

Reviewer: H.Irschik (Linz)

MSC:

74L15 Biomechanical solid mechanics
92C10 Biomechanics
70Q05 Control of mechanical systems
70H20 Hamilton-Jacobi equations in mechanics
70K20 Stability for nonlinear problems in mechanics

Keywords:

neuromuscular stimulation; musculoskeletial motion; Lagrange's equations; joint torque; optimal control problem; Hamilton-Jacobi equation; Lyapunov function theory; global asymptotic stability; parameter identification

Full Text: DOI

References:

[1] Agarwal, G.C.; Gottlieb, G.L., Mathematical modeling and simulation of the postural control loop, CRC crit. rev. biomed. eng., 12, 2, 49-93, (1985), Part III

[2] Albus, J.S., A theory of cerebellar function, Math. biosci., 10, 25-61, (1970)

[3] Andersson, D.J.; Reschke, M.F.; Homick, J.E.; Werness, S.A., Dynamic posture analysis of spacelab-1 crew members, Exp. brain res., 64, 380-391, (1986)

[4] Arnold, V.I., (), 255

[5] Åström, K.J.; Wittenmark, B., Adaptive control, (1989), Addison-Wesley Reading, Mass · Zbl 0217.57903

[6] Basmajian, J.V.; De Luca, C.J., Muscles alive—their functions revealed by electromyography, (1985), Williams and Wilkins Baltimore

[7] Belitskii, V.V.; Chudinov, P.S., Parametric optimization in the problem of biped locomotion, Mech. solids, 12, 22-31, (1977)

[8] Burbaud, P.; Garanx, F.; Gross, C.; Bioulac, B., Postural adjustments in the monkey: effects of velocity on EMG sequence, Neurosci. lett., 84, 51-56, (1988)

[9] Carlsöö, S., The static muscle load in different work positions: an electromyographic study, Ergonomics, 4, 193-211, (1961)

[10] Ceranowicz, A.Z.; Wyman, B.F.; Hemami, H., Control of constrained systems of controllability index two, IEEE trans. autom. control, AC-25, 1102-1111, (1980)

[11] Chizeck, H.J.; Crago, P.E.; Kofman, L.S., Robust closed-loop control of isometric muscle force using pulsewidth modulation, IEEE trans. biomed. eng., BME-35, 510-517, (1988)

[12] Chow, C.K.; Jacobson, D.H., Studies of human locomotion via optimal programming, Math. biosci., 10, 239-306, (1971) · Zbl 0215.59305

[13] Craig, J.J.; Hsu, P.; Sastry, S.S., Adaptive control of mechanical manipulators, Int. J. robotics res., 6, 2, 16-28, (1987)

[14] Fleming, W.H.; Rishel, R.W., (), 94-97

[15] Goldstein, H., (), 273, ff.

[16] Golliday, C.L.; Hemami, H., An approach to analyzing biped locomotion dynamics and designing robot locomotion controls, IEEE trans. autom. control, TAC-22, 963-972, (1977)

[17] Goodwin, G.C.; Sin, K.S., Adaptive filtering, prediction and control, (1984), Prentice-Hall Englewood Cliffs, N.J, Chap. 6 · Zbl 0653.93001

[18] Grillner, S., Locomotion in vertebrates—central mechanisms and reflex interaction, Physiol. rev., 55, 247-304, (1975)

[19] Grillner, S.; Dubuc, R., Control of locomotion in vertebrates: spinal and supraspinal mechanisms, Adv. neurol., 47, 425-453, (1988)

[20] Grillner, S.; Wallén, P., Central pattern generators for locomotion, with special reference to vertebrates, Annu. rev. neurosci., 8, 233-261, (1985)

[21] Haas, G.; Diener, H.C., Development of stance control in children, (), 49-58

[22] Hahn, W., Stability of motion, (1967), Springer-Verlag New York, Chap. IV and Section 55 · Zbl 0189.38503

[23] Hatze, H., A complete set of control equations for the human musculo-skeletal system, J. biomech., 10, 799-805, (1977)

[24] Hatze, H., Neuromusculoskeletal control system modeling—a critical survey of recent developments, IEEE trans. autom. control, TAC-25, 375-385, (1980) · Zbl 0432.92005

[25] He, J., A feedback control analysis of the neuro-musculo-skeletal system of a cat hindlimb, ()

[26] Hebb, D.O., The organization of behaviour, (1949), Wiley New York

[27] Hemami, H., Modeling, control, and simulation of human movement, CRC crit. rev. biomed. eng., 13, 1-34, (1985)

[28] Hemami, H.; Chen, B.R., Stability analysis and input design of a two-link planar biped, Int. J. robotics res., 3, 93-100, (1984)

[29] Hemami, H.; Farnsworth, R.L., Postural and gait stability of a planar five link biped by simulation, IEEE trans. autom. control, AC-22, 452-458, (1977)

[30] Hirose, S., Active coordination mechanisms, ()

[31] Hogan, N., The mechanics of multi joint posture and movement control, Biol. cybern., (1985) · Zbl 0599.73101

[32] Houk, J., Regulation of stiffness by skeletomotor reflexes, Annu. rev. physiol., 41, 99-114, (1979)

[33] Houk, J.; Zev Rymer, W., Neural control of muscle length and tension, ()

[34] Ito, M., The CNS as a multivariable control system, Behav. brain sci., 5, 552-553, (1982)

[35] Johansson, R., Parametric models of linear multivariable systems for adaptive control, IEEE trans. autom. control, AC-32, 303-313, (1987) · Zbl 0627.93038

[36] Johansson, R., Lyapunov design for adaptive control of robots, Proceedings of the IFAC nonlinear control systems design symposium, (1989), Capri, Italy

[37] Johansson, R.; Magnusson, M.; Åkesson, M., Identification of human postural dynamics, IEEE trans. biomed. eng., 35, 858-869, (1988)

[38] Johansson, R., Adaptive control of robot manipulator motion, IEEE trans. robotics and automation, 6, 483-490, (1990)

[39] Lacquaniti, F.; Maioli, C., The role of preparation in tuning anticipatory and reflex responses during catching, J. neurosci., 9, 134-148, (1989)

[40] Lee, C.S.G., Robot arm kinematics, dynamics and control, IEEE comput., 62-80, (1982)

[41] Lee, E.B.; Markus, L., (), 348, Theorem 7

[42] Levine, W.S.; Zajac, F.E.; Belzer, M.R.; Zomlefer, M.R., Ankle controls that produce a maximal vertical jump when other joints are locked, IEEE trans. autom. control, AC-28, 1008-1016, (1983) · Zbl 0515.93030

[43] Liddell, E.G.T.; Sherrington, C.S., Reflexes in response to stretch (myotactic reflexes), Proc. roy. soc. London B, 96, 212-242, (1924)

[44] McCloskey, D.I.; Gandevia, S.; Potter, E.K.; Colebatch, J.G., Muscle sense and effort: motor commands and judgements about muscular contractions, (), 151-167

[45] Magnus, R., Some results of studies in the physiology of posture, Lancet, 211, ii, 531-536, (1926), (Cameron Prize Lectures)

[46] Marsden, C.D., Which motor disorder in Parkinson's disease indicates the true motor function of the basal ganglia?, Ciba found. symp., 107, 225-241, (1984)

[47] C. D. Marsden, P. A. Merton, and H. B. Morton, Anticipatory postural responses in human subjects, \textit{J. Physiol. London}, 275:47-48.

[48] Mori, S.; Takakusaki, K., Integration of posture and locomotion, (), 341-354

[49] Nashner, L.M., Conceptual and biomechanical models of postural control strategies for organization of human posture, Proceedings of the 7th int. symp., int. society of posturography, 1-8, (1983), Houston, Texas

[50] Parks, P.C., Lyapunov redesign of model reference adaptive control systems, IEEE trans. autom. control, AC-11, 362-365, (1966)

[51] Paul, R.P., Robot manipulators—mathematics, programming and control, (1981), The MIT Press Cambridge, Mass

[52] Roland, P.E., Sensory feedback to the cerebral cortex during voluntary movement in man, Behav. brain sci., 1, 129-171, (1978)

[53] Sanes, J.N.; Jennings, V.A., Centrally programmed patterns of muscle activity in voluntary motor behavior of humans, Exp.

brain res., 54, 23-32, (1984)

[54] Saridis, G.N.; Lee, C.S.G., An approximation theory of optimal control for trainable manipulators, IEEE syst., man, cybern., SMC-9, 152-159, (1979) · Zbl 0398.49001

[55] Seireg, A.; Arvikar, R.J., A mathematical model for evaluation of forces in lower extremities of the musculo-skeletal system, J. biomech., 6, 313-326, (1973)

[56] Seireg, A.; Arvikar, R.J., The prediction of muscular load sharing and joint forces in the lower extremities during walking, J. biomech., 8, 89-102, (1975)

[57] Shapovalova, K.B.; Poltavets, S.P.; Boiko, M.I., Vliianie stimulatsii golovki khvostatogo iadra na aktivnost' poznykh myshts pri realizatsii oboroni-tel'nogo refleksa, Fiziol. zh. SSSR, 68, 1488-1499, (1982)

[58] Söderström, T.; Stoica, P., (), 62

[59] Thorstensson, A.; Oddsson, L.; Carlsson, H., Motor control of voluntary trunk movements in standing, Acta physiol. scand., 125, 309-321, (1985)

[60] Viallet, F.; Trouche, E.; Beaubaton, D.; Nieoullon, A.; Legallet, E., Motor impairment after unilateral electrolytic lesions of the substantia nigra in baboons: behavioral data with quantitative and kinematic analysis of a pointing movement, Brain res., 279, 193-206, (1983)

[61] Vukabratović, M.; Kirćanski, N., A method for optimal synthesis of manipulation robot trajectories, J. dynamic syst. measurement, control, 104, 188-193, (1982) · Zbl 0508.93028

[62] Vukabratović, M.; Juricic, D., Contributions to the synthesis of biped gait, IEEE trans. biomed. eng., BME-16, 1-6, (1969)

[63] Widrow, B.; Stearns, S.D., Adaptive signal processing, (1985), Prentice-Hall Englewood Cliffs, N.J · Zbl 0593.93063

[64] Widrow, B.; Winter, R., Neural nets for adaptive filtering and adaptive pattern recognition, IEEE comput., 25-39, (1989)

[65] Zattara, M.; Bouisset, S., Posturo-kinetic organization during the early phase of voluntary upper limb movement. 1. normal subjects, J. neurol. neurosurg. psychiatry, 51, 7, 956-965, (1988)