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論文題名 Analytical Method for Synergy Based Motion Control Supported by Joint Energy and Coordination Measure Toward Rehabilitation and Robotics

研究論文の概要

Rehabilitation robotics is to provide an appropriate coordination between human motion behavior and the robot motion and two important issues are motion trajectory design to resolve problem of the degree of freedom and optimization of the energy consumption. The well-coordinated motion coupling with robotic tools contributes to recovering the natural motion behavior by supportive forces to complement weakened muscular activities. Dealing with the first issue of motion trajectory design, the study focused on the approach of synergy theory. The synergy hypothesis was originally proposed as a biological scheme of hierarchal coordinated muscle activation to generate well-coordinated motion behavior. The synergy approach of motion behavior generation in humanoid robot is an effective solution for degree of freedom and coordination problem. As a analytical method, this study dealt with developments of algorithm to find well-coordinated motor synergy and further to calculate the characteristic synergy signal with minimum energy and maximum coordination. Firstly, an extended method based on Principal Component Analysis (PCA) to analyze the structural, or spatio-temporal coordination in the human behavior was proposed. The original PCA has been widely used for data analysis that can be represented by multi-dimensional vectors and signals in a time course to find hidden internal factors. However in the human behavior there are unclear coordination factors depending on body parts and time based transitions of coordination patterns corresponding to motion behavior. To analyze the hidden synergy to the humanoid body kinematics during regenerated human motion. By integrating the Via-point method to the time stepwise PCA, an analytical method was proposed in consideration of the human body kinematics and validated in the humanoid robot platform, Aldebaran NAO. The proposed extended algorithms were 1) PCA Body by Part (BP) to focus on a separate limb synergy, 2) PCA Time by Part (TP) to find “the critical joint” which is assumed to a representative joint for the control by the central nervous system, and its combination of 3) PCA Time by Part-Body by Part (TP-BP), and 4) PCA Body by Part-Time by Part (BP-TP). Those algorithms are validated in their performance of the motion reproduction and demonstrated how the hidden synergy can be analyzed by changing analytical tools as proposed 1-4) algorithms.

Regarding the second issue of appropriate torque generation in motion with minimum energy consumption, an analytical method based on the four-linkage human body model including kinematics and dynamics were established. The method is applied to compare the human motion analysis and artificial trajectory based motion generation. In the model, hip, knee and ankle joints were induced and the recording data from the VICON 3D motion capture device. The sitting-and-standing motions capture data was applied to the numerical simulation of the model in MATLAB. By calculating the via-point of human motion trajectory, the artificial trajectory is obtained by interpolation methods of Quintic, Cubic, LSPB. Furthermore, torque and consumed joints energy for human trajectory were calculated and compared artificial motion trajectory. The comparison shows the LSPB interpolation has a consistency with the human motion in the viewpoint of the minimum energy and minimum error of trajectory. A method to estimate the best number of via-points is developed on the basis of error comparison graph. The mathematical estimation of number of via-points benefits for the implementation of the Time by Part synergy method.

In conclusion, the proposed analytical method in this study is helpful to promote the establishment of effective analyses of joint energy and coordination in the human body. The analysis method contributes to the motion trajectory generation with respect to the degree of freedom and minimum energy toward the realization of expected human motion coordination in the rehabilitation robotics.