論文の内容の要旨
Abstract of Dissertation

論文題目　Quantitative Estimation of Muscle Fatigue in Handgrip Tasks using Surface Electromyography

（表面筋電位センサを用いた把持作業時の筋疲労の定量的評価）

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（本文）(Abstract)

Muscle fatigue is commonly associated with the musculoskeletal disorder problem. Since muscle fatigue is not a physical parameter, it is impossible to measure the value directly. Previously, various techniques were proposed to index the muscle fatigue relying on other parameters that are correlated to the development of muscle fatigue. However, the fatigue index is commonly used to observe the onset of muscle fatigue, instead of quantifying the discrete value. The goal of this study is to propose a practical method so that the degree of muscle fatigue can be estimated quantitatively.

This study is carried out in two stages. In the first stage, the study is focused on isometric muscle contraction. Here, the model of muscle fatigue is constructed by assuming that it is equivalent to the force loss after performing some muscular work. In addition, we proposed a method to estimate the muscle fatigue from surface electromyography (SEMG) signal to replace the dynamometer. This is because the non-invasive and non-intrusive characteristic is essential, when its practicability is a major concern. As for the second stage, the modeling of muscle recovery is proposed. This model is used to estimate the amount of muscle fatigue that is recovered over time. By integrating both fatigue and recovery model, we are able to quantify the muscle fatigue for dynamic muscle contraction.

The main function of the force estimation model is to compute the handgrip force from SEMG signal during fatiguing muscle contraction tasks. The appropriate frequency range was analyzed using various combinations of a wavelet scale, and the highest accuracy was achieved at a range between 242 Hz and 365 Hz. After that, eight healthy individuals performed a series of isometric contraction tasks (20%, 30%, 50%, and 70% MVC) and dynamic contraction tasks (0 – 50% MVC) to evaluate the performance of this technique. The comparison is made with the former method that based on the root mean square of SEMG signal. Both methods had comparable results at the beginning of the experiments, which is before the onset of muscle fatigue. However, differences were clearly observed as the degree of muscle fatigue began to increase toward the endurance time. Under this condition, the estimated handgrip force using the proposed

method improved by 5% to 40% for isometric contraction tasks and 40% for dynamic contraction tasks. This study overcomes the limitation of the earlier method during fatiguing muscle contraction tasks and, therefore, unlocks the potential of utilizing the SEMG signal as an indirect force estimation method.

The fatigue model is proposed as the solution to quantitatively estimate the degree of muscle fatigue. An exponential-based fatigue model is constructed that represents the relationship between the handgrip work and the maximal voluntary contraction loss, is constructed. In this study, it is assumed that the force loss due to the muscular work is equivalent to the degree of muscle fatigue. With the force estimation model, the degree muscle fatigue can be quantified from the handgrip force estimated using the SEMG signal captured from the forearm muscles. Eight male subjects volunteered in this study to perform a series of isometric handgrip tasks at three different contraction levels. First the fatigue model is calibrated for each subject. Then, the degree of muscle fatigue is estimated based on the amount of handgrip work performing in the tasks. The evaluation is carried out by comparing the force loss that is measured by a dynamometer and the one estimated using the SEMG signal. On average, the estimated error is less than 10% MVC. The error is correlated to the force level estimated from the SEMG signal since the handgrip work is the independent parameter of the proposed fatigue model.

The recovery model is proposed to represent the relationship between the muscle fatigue and the recovery durations. Three experiments were conducted at 50% MVC with the contraction time of 10 s, 30 s and 50 s. Every experiment consists of 5 handgrip tasks with different rest interval. The maximal isometric forces during the pre-fatigue and post-fatigue were recorded to compute the muscle fatigue developed from each handgrip tasks. An exponential function is used to model the relationship between the muscle recovery and rest interval. With this model, the amount of muscle fatigue that is recovered given the rest duration can be estimated. This is important especially during dynamic muscle contraction.