Discussion of Alternating Muscular Activity for the Design of an Automatic Saddle Positioning System

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Abstract: This study has been aiming to develop a system that optimizes the mechanical settings of a cycle road racer against rider's physical properties. At present, even skilled cyclist, riders have to rely on their riding feelings and/or advice of trainer, coach, and expert rider. Neither numerical evaluation method nor effective instrument has been used. Therefore, most of cyclists strongly desire the system that helps to find the best positions of saddle and handle only keeping pedaling motion on the experimental device. Now, the authors are constructing an automatic saddle positioning device, in which saddle's horizontal position, longitudinal height, and angle are automatically controlled during pedaling motion. These degrees will be adjusted by the basis of analyzing muscular activity data of lower limbs deeply related in pedaling exercise. Surface electromyography (SEMG) of lower limb is measured to estimate the muscular activity of each muscle. In addition, the muscular activity form of lower limb in pedaling motion is evaluated with principal component analysis. This paper describes a system structure, an experimental protocol, and discusses the experimental results.

Keywords: Surface electromyography, cycling exercise, bio-signal processing

1. INTRODUCTION

Recently, cyclist numbers have been increasing against the social background about health trend, rising crude oil prices, and global heating. Riders, especially cycle road racers, commonly employ a binding pedal system which fixes between cycling shoes and pedals to effectively convert the physical activity to propulsion of a bicycle. Thereby, they have to properly adjust the bicycle equipment such as saddle and handle against rider's physical properties. It is impossible for us to know the other people sensation of movement, and neither method nor instrument has been proposed. Then the authors have been engaging in the development of a system that automatically find the best saddle height by referencing to both skilled cyclist's pedaling motion and his subjectivity for saddle height setting, in which the pedaling motion was quantitatively estimated and analyzed by using surface electromyography of lower limb muscles that are deeply related in pedaling motion. In the previous work, the authors had constructed an experimental system. This system was composed of a commercially available cycle ergometer, a lab-made saddle height control device, and surface electromyography (SEMG). All they are connected to a personal computer to feedback control the saddle height control device. As subjective muscles of a rider, five lower limb muscles such as biceps femoris, lateral vastus, rectus femoris, and both inner and outer triceps surae, were selected. Their SEMG signals were processed by First Fourier Transform, in which the max value of power spectrum was adopted as muscular activity. And the authors designed a fuzzy control law based on the muscular activity form and the subjective riding sensation of a skilled cyclist. Finally, the experiment was conducted on two rider, one is a skilled rider and the other is a beginner. But, regardless of rider's cycling skill, the saddle height continuously declined after a certain period of time from the start of experiment [1]. As the cause of this result, it can be considered that the muscular activation form of lower limb changes while an experiment. It has been well known that muscle fatigues in exercise, and its fatigue properties appeared on surface electromyography have two kinds of features. One of them is qualitative alteration, in which frequency of SEMG signal declines according to fatigue accumulation. The other feature is qualitative alteration, in which amplitude of SEMG signal increases according to fatigue accumulation. Though the muscular fatigue features appeared on SEMG signal have been found, the causes of them have not been clearly understood. Then, this study investigate the muscular activation form during pedaling exercise in order to grasp the feature quantities of pedaling motion of a cyclist. In this paper, we firstly introduce the related works. And the measurement system for pedaling motion and the measurement protocols are described. Finally, the experimental results are discussed.

2. RELATED WORKS

Gonzalez and Hull advocated the importance of personalized bicycle based on the anthropometry [2]. According to the interview of a skilled cyclist and our survey findings, we fully comprehend the significance of bicycle position settings depending on the rider's physical features. Yoshihuku [3] found the optimal values of bicycle parameters from muscles of the human lower limb during pedaling exercise, which maximized the power of pedaling. For the setting of bicycle components, especially the saddle height has a great impact for pedaling performance. The saddle height is
defined as the distance from the saddle surface to the center of clank in a straight line along seat pillar. To find an effective height for pedaling performance based on biological reaction of human body, Hamley and Thomas [4] concluded that the most efficient saddle height is 109% of symphysis pubis height (inseam) by using oxygen consumption, and other studies including the effort of [5] also confirmed that this method provides optimum aerobic power. Holmes had recommended using 109% of inseam for eliciting high performance, and using 25-35 knee angles for injury prevention [6]. Peverel et al. compared a saddle height of 109% of inseam with 25-35 knee angle from the viewpoint of anaerobic power production by using a 30s Wingate test, and showed that using the 25-35 knee angle produces better results than 109 % of inseam [7]. However, a problem about above reports can be indicated. Today, variety of pedals, cleats, and the shape of saddle made a considerable impact to their reference variables. Because of these factors, evaluating biological information has been considered to be acceptable and useful to find an efficient setting. Mary researchers remain a lot of remarkable knowledge, however the relation between cycling skill and muscle activity for road racer has been still unmentioned.

3. METHODS

3.1 System structure

Fig. 1 shows a schematic diagram of the system the authors have been designed that is a feedback control system of a saddle height control device based on physical exertion signals. A saddle positioning device is under construction which has three degrees of freedoms; vertical freedom along the seat tube of a bike, horizontal freedom, and horizontal angular freedom. This study adopts surface electromyography of lower limb muscles as mentioned above.

The purpose of this paper is to investigate dynamic statement of muscular activity during pedaling exercise in order to specify the feedback signal to control the saddle positioning device.

Then this study prepared one skilled cyclist who has over 10 years cycling career and his road bike. The employment of low number of subjects has been adopted even in the related works to investigate the trend of muscular activity. Because there is a possibility of the measured data spreads. Then, in most of related works, a skilled cyclist who has the actual performance of cycling competition was employed.

Fig. 1 is his road bike, where the tail wheel’s shaft is fixed with a commercially available cycle trainer (ELITE Inc. Super Crono Power Fluid). The trainer has been used by professional cyclists all over the world, and can provide realistic riding feelings to trainees. Here, the positions of the saddle and the handle are empirically settled by the skilled cyclist. This study adopts it as the experimental equipment as substitute for a cycle ergometer system to avoid the absence of rider’s usual riding feelings and pedaling skill.

Lower limb muscles which are thought to be important for pedaling exercise are selected as subjective muscles. Electrodes for SEMG measurement are patched on the surface of subject’s leg; 1ch: Rectus femoris (RF), 2ch: Lateral vastus (LV) 3ch: Biceps femoris (BF), 4ch: Anterior tibialis (AT), 5ch: triceps surae (TS) as decribed in Fig. 3. These SEMG signals are measured at 1000 Hz sampling rate and input to a computer via 12bit AD conversion board.

3.2 Experimental protocol

Through the experimental measurement conducted in this paper, this study instructs a subject to keep 90 rpm of the pedaling rates. This number of rotation speed is considered to be the most efficient rotation period by many skilled professional cyclists. Most of cyclists

![Fig. 3 Schematic diagrams of lower limb muscles selected as the subjective muscles](image3.png)
pedals as 90 rpm or greater while riding on a flat road [8]. Also it was reported that effective recruitment of muscle fibers might be achieved by sustained pedaling at 90 to 100 rpm [9].

Handle is also one of the important of bicycle, but is highly depending on the setting of saddle. This paper examines the differences of SEMG signals depending on the saddle height and the pedaling load. Saddle height is changed to 5mm low and high against the normal height of 667mm. Two deferent pedaling loads can be realized by changing the gear ratio. The one pedaling load is about 150W (Light) and the other is about 250W (Heavy). SEMG signals are measured in total six combinations of three different saddle height and two different pedaling loads. In order to avoid the influence of fatigue due to the previous pedaling exercise, there is enough rest of over 5 minutes among the experiments.

3.3 Signal processing

To investigate dynamic statement of muscular activity of lower limb during pedaling exercise, firstly each amount of muscular activity has to be quantitatively estimated from wave shape SEMG signal. Root mean square (RMS) method is adapted to process SEMG signal for one cycle of pedaling, then the amount of muscular activity spent to rotate one cycle of pedal can be estimated. After all, by using this RMS method, the muscular activities of five lower limb’s muscle are computed, and time-series of each muscular activity rate can be calculated. This study has been using principal component analysis (PCA) to evaluate muscular activity form of lower limb, where the scores of PCA result record the number of pedaling motion. Thereby, the dynamic statement of muscular activity of lower limb will be clarified.

4. RESULTS

The activity rate of each muscle every one minute during pedaling exercise is described in Fig. 4, in which total six patterns of combination between saddle height and pedaling load are shown, respectively. This percentage of muscular activity rate means the rate of each muscular activity against the sum total of all muscles’ activity equals to one hundred percentages. Then it can be thought that these graphs are indicating absolute activity rate of each muscle, and these graphs clarified that muscular activity are unstable during pedaling exercise.

Next, this paper applied PCA to RMS data of all channel's SEMG data, in which correlation matrix is adopted to evaluate each muscular activity relatively. PCA results are shown in Fig. 5. All scores were calculated by every pedaling motion, and they recorded the number of pedaling motion. In this result, the scores are colored by the time of pedaling exercise. In all cases, cumulative contribution ratio of summation between the first principal component score and the second principal component...
Fig. 5 PCA results, in which a vertical axis is the first principal component coefficient (PCC) and a horizontal axis is for the second PCC. Their rightward score sheet shows every one minute's average.
score exceeded 80%, then this paper adopted two dimensional score sheet. In addition, the rightward figures describe the transitions of the average score of each minute.

5. DISCUSSIONS

According to the knowledge of biomechanics, BF and AT acts well in pressing motion, by the way BF and TS are used in pulling motion. RF and LV are used in up-and-down movement of a knee. To realize smooth pedaling motion, a rider has to not only press into the pedal but also pull up the pedal by been aware of pedaling motion, a rider has to not only press into the pedal but also pull up the pedal by been aware of pedaling motion.

From the results presented in Fig. 4, no great variation of the muscular activity rate of RF and LV are confirmed. This means the pedaling motion is less affected by movement muscles of RF and LV. By the way, the other muscles altered widely. Especially, a great alternation of muscular activity rate of BF and AT occurred in the normal height experiment shown in Fig. 4(b) and Fig. 4(e). The total activity balance became better by increasing pedaling load from 150 W to 250W. According to the subjective evaluation of the skilled cyclist subject for the change of pedaling load at the same normal height, it made better to smoothly rotate the pedal. The pedaling load of 150 W is too light for this subject to smoothly move the legs. In the view of this, we especially focused on the experimental result of the normal height condition.

This study implemented PCA on the five channels’ RMS data based on a hypothesis that PCA score can describe the dynamic statement of muscular activity of lower limb. All PCA scores of Fig. 5 record the number of pedaling motion and are plotted on two dimensional PCA score sheet. From Fig. 5, a member of trends of transitions of the average score on the PCA score sheet during pedaling exercise. First, except in the cases of Fig. 5(a) and Fig. 5(e), the average score described in the right figure of 2-3 minute declines along the vertical axis. This means that the second principal component score decreased sharply. Meanwhile, both of the first principal component score shown in Fig. 5(a) and Fig. 5(e) raised and fell contrastively without falling the second principal component score like other figures. As the cause of falling the second component score at 2-3 minute confirmed in Fig. 5(b), (c), (d), and (f), the effect of muscular fatigue is doubted. In the experiments implemented under the high pedaling load condition, the muscles were forcibly tired within two or three minutes. Hence, regardless of saddle height, the second principal component score fell with experimental time. Namely, this study considers that an improper saddle height stimulates five muscles disproportionately, then the effect of muscular fatigue appears only a part of the subjective muscles.

To enhance the proposed method, this study is going to continuously accumulate the data of the same skilled subject by periodically managing his physical conditions. The thing this study found through the experiments, the lower limb’s muscles begin to fatigue in well-balance even under the condition of light pedaling load. Our next work is to prove the dynamic statement of muscular activity with more skilled cyclists based on PCA results, and is to specify the method to produce the feedback signal from SEMG signals.

6. CONCLUSIONS

This study has been designing a system that helps to optimize the mechanical setting of a road bike. As the fundamental research, this paper investigates the effect of saddle height against SEMG signals of lower limb muscles which deeply relates with pedaling motion. This study clarified that the muscular activity rate changes during pedaling exercise. And the muscular activity form which was evaluated by the PCA score sheet are also changing according to a manner. The effect of muscular fatigue appeared after two or three minutes from the start of experiment. The appearance of muscular fatigue might be related to the saddle height. For future work, this study investigate the effect of muscular fatigue about each subjective muscle by using time-frequency analysis method such as continuous wavelet transform.

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REFERENCES


