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Predicting the Individual Best Saddle Height of Bicycle Based on Electromyography and Fuzzy Inference

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Abstract— **Recently, various social issues, such as global warming problem, economical abrupt move, and diseases associated with adult lifestyle habits, are reported. Against them, the role of bicycle has been reviewed as one of effective solutions. In fact, many types of bicycles have been developed and have been widely used in our daily life. Though commercially available bicycles have various size of frame for user's physical size, and the positions both of a saddle and a handle can be modified, but there is a lack of interests in the importance of bicycle position as a shared awareness. Provision of proper riding posture for riders based on their physical properties would enable to improve the efficiency of cycling exercise, and to prevent some chronic pains occurred in places of body. To establish an optimization method of bicycle position based on individual biomedical information, this study focuses on the importance of bicycle position, especially we address to search a suitable saddle height corresponding to user's physical features and properties. This paper firstly develops an automatic saddle height control system, and secondly supposes an evaluation standard of cycling exercise based on electromyographic signals of rider's leg during cycling exercise, and an optimization method of saddle height by using Fast Fourier Transformation (FFT), Principle Component Analysis (PCA), and Fuzzy Inference. This paper shows firstly the concepts of the evaluation standard we have defined for rider's pedaling performance with some experimental results, and introduces a fuzzy control system for automatic saddle height control.**

I. INTRODUCTION

Since bicycle had the general design similar to that of today in the beginning of the 20th century, millions of bicycles are used daily for transportation, recreational or competitive cycling. In these days, the roles of bicycle have been reviewed in confrontation with several social issues, such as global warming, unstable crude oil price, and health problems of developed nations. This vehicle needs no fossil fuel and pours out no CO_2, and its maintaining cost is more reasonable than other auto vehicle, moreover its mechanism effectively converts human physical load to its kinematic energy [1]. According to the mentioned reasons, adoption rate of bicycle is widely spreading in a variety of fields, such as rehabilitation exercise, one of the ways of daily commute to work, and holiday's relaxation sport, etc. Popularity of cycling sports is gradually increasing along with the development of multimedia, especially the people who are not specifically trained begin to ride on a bicycle for their physical fitness and holiday's recreation. Meanwhile, there is few concerns for the importance of bicycle position. A position of bicycle is the equipment initialization determined by the settings of saddle and handle. It has already reported that performance in cycling is affected by various factors, including aerobic and anaerobic capacity, muscular strength and endurance, and body composition [2]. Moreover, we consider that a bicycle position involves the performance of cycling exercise deeply, because the bicycle position dominates a basic riding posture and a pedaling form. But, available determining method of the bicycle position have been blurred and now it is determined empirically from user's riding experience. Within our inquiry, there are few researches investigating the effects of different sittings of bicycle to a performance of cycling by the basis of biological information.

This study aims to establish an optimization method of the saddle height of bicycle corresponding to individual physical properties of riders. Especially, we have focused on leg muscular activities during cycling exercise, and we have assumed that the leg muscles activate relatively and evenly at the rider's best saddle height. Probably a good position might vary with each individual even users are similar in size to height and weight, because their physical features such as the length of each body part and articular flexibility are definitely not the same. If it becomes possible to optimally fit the bicycle position against rider's physical features before riding, we would be able to obtain comfortable cycling life and exercise efficiency higher than ever before with less physical burden. Moreover, if it becomes possible to easily make the optimal settings of bicycle for users, we can use bicycle more effectively and healthfully. For our fundamental study, we have restricted the degrees of freedom of bicycle's position to only one degree of freedom of saddle height and have employed a binding shoes in order to fix between the pedals of bicycle and the bottoms of rider's feet. A handle of bicycle used in our experiment is previously fastened to appropriate position by a subject, and it never changes during experiment. Due to its convenience, the extraction of information from the electrical signal generated by the activated muscles (EMG) has been regarded as an easy way to evaluate muscular activities, and has been used in various fields of researches. Many researchers have provided a review of the pedaling technique using an EMG approach, and have shown how the pattern of muscle activation during pedaling can be analyzed in terms of muscle activity level and muscle

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activation timing. In order for our system construction, we firstly establish the gold standard evaluation for the rider's pedaling performance with one skillful cyclist. Muscular activations during pedaling exercise of skilled riders are more stable and suitable for evaluate pedaling performance than inexperienced riders. For the same subject, we measure his leg electromyography data during pedaling exercise, and apply both of FFT and PCA to the data. And then a fuzzy inference is adopted to predict the best saddle height for the subject. Some experimental results show that our proposal techniques have a possibility to seek the most suitable saddle height of bicycle form rider's physical properties.

II. RELATED WORKS

About pedaling exercise, there has been a lot of interest in physiological response, mechanical efficiency, maximum force output [3] and cardiorespiratory response [4]. Although pedaling is constrained by the circular trajectory, it is not a simple movement. In sport and applied physiology, EMG techniques are spreading as an assessment tool, so their usage is now well accepted by various researches [5]. The pedaling exercise is no exception of this. Hug et al. have provided a review of the pedaling technique using an electromyographic (EMG) [6]. They showed analysis methods for the pattern of muscle activation during pedaling, and also described whether the patterns of the lower limb muscles activity are influenced by numerous factors affecting pedaling such as power output, pedaling rate, body position, shoes pedal interface, training status and fatigue. In pedaling exercise, the amount of exhaled carbon dioxide begins to increase rapidly after attainment of a certain exercise stress due to the generation of lactic acid that is fatigue agent of muscle [7]. EMG analysis provides threshold amount of lactic acid generation [8], so it has been widely thought that EMG is one of the most efficient technique for muscle fatigue evaluation. EMG has also been thought to serve many uses for clinical discipline [9] because of its availability for the estimation of backache [10] and nervous disease of the motor system [11].

The fast Fourier transform (FFT) and discrete Fourier transform (DFT) algorithms are commonly used to derive the EMG power density spectrum [12][13]. Lately as a substitute technique for FFT, wavelet transform approach, which is localized in both time and frequency whereas the standard Fourier transform is only localized in frequency, has been frequently used for the analysis of EMG [14] including bicycle ergometer exercise [15], and its effectiveness has also been reported. But in this study, we adopt FFT fully-established as a proven method to control ergometer [16].

In cycling sports, it has been thought that cyclists empirically optimize the pedaling performance by changing riding posture depending on the situation [17]. As interesting previous works, we can here show that Andrew et.al, investigated the differences of leg muscular activity pattern between novice cyclists and trained cyclists [18], and the influence of riding posture onto muscular recruitment [19]. N.Bessot et. al, reported the influence of pedal cadence alteration to muscle activity and pedal force production [20]. Kigoshi et.al, revealed the effects of the different saddle height setting on hip extension muscle activation and maximum power by using EMG as biological information [21].

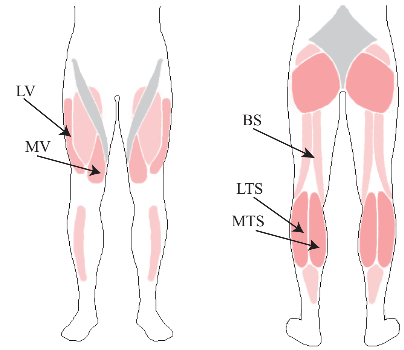

Fig. 1. Leg muscular parts to be measured

It is considered that the extension-flexion of body trunk might have a great influence on the muscle activation during pedaling exercise, because the cycling exercise is limited to specific posture. One of the most typical output is muscle fatigue, so an increasing number of analysis result of this have been reported. Based on the results, it can be assumed that an appropriate cycling exercise is not with the localized accumulation of muscle fatigue, but with homogeneous [22]. However we could not find a report dealing with interactive and intelligent optimization method of bicycle position to distribute the muscle fatigue. As an example of previous effort on bicycle with intelligent processing, this paper can show the work by Kiryu et al. that aimed to control the load of ergometer by using fuzzy inference and principal component analysis [23]. This paper develops real-time search algorithm in accordance with the Kiryu's effort.

III. METHOD

A. Establishment of numerical evaluation standard

In order to establish an evaluation standard that evaluates subject's pedaling performance, we have employed leg electromyographic signals as individual physical information, where five electrodes are patched on the surface of subject's leg as shown in Fig. 1. The muscles that electrodes are patched on in our study are the following ones; lateral vastus (LV), medial vastus (MV), biceps femoris (BS), medial triceps surae (MTS), and lateral triceps surae (LTS). We assumed that these muscles work better in pedaling exercise and these muscular activities can be easily detected by using EMG. To make it possible to measure electromyographic signals at 1000 Hz sampling rate, we applied some Windows API functions to Visual Basic 2005. Fig. 2 shows an example of raw electromyograph data measured from LV. The electromyography data is measured in pedaling exercise at 90 revolutions per minute.

From raw electromyographic data, we derive a power spectrum data through First Fourier Translation (FFT), where Hann window function is applied to 64 EMG data. In order to evaluate a total amount of power spectrum for one

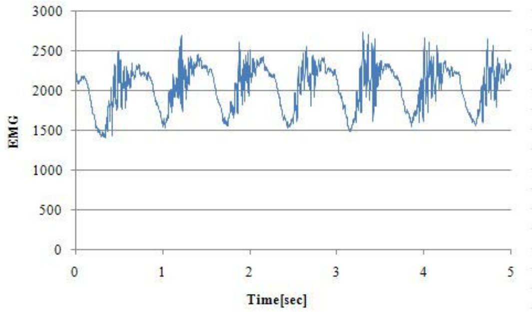

Fig. 2. Raw electromyographic data of LV

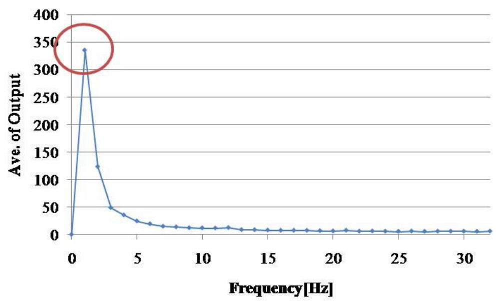

Fig. 3. Averaged power spectrum data of EMG of LV

revolution of pedaling, after ten times FFT implementation, the averaged power spectrum data is derived and it is used as muscular activity data in this study. Power spectrum data contains some electric noises through entire frequency band, so that we use only the peak value of the averaged power spectrum data, shown in Fig. 3, as the amount of activity of muscles per unit time during pedaling.

After three times calculation of the muscular activity, we applied principal component analysis method (PCA) to the obtained muscular activity data. PCA is a mathematical procedure that evaluates overall feature of one data and/or small group of data against entire data under synthesizing elements that have a correlation with each other and making a variety of components. In our study we adopt first and second principal component because the total amount of their contribution rate exceeds over 84% according to the experimental results we have already confirmed these results several times. In order to evaluate the changes of muscular activities before and after the saddle height changes, we have built an on-line usage algorithm of PCA. According to the features of PCA, the meanscore of PCA comes close to the center of score sheet composed of the first and the second principal components. The data plotted near the center of score sheet can be considered as that they have no characteristics against entire data, against them some characteristic data is plotted getting away from the center. Especially, the favorable data will be plotted in the first quadrant. And then we made a hypothesis that the averaged score of PCA after changing the saddle height from wrong height to proper height for a subject moves toward to the first quadrant.

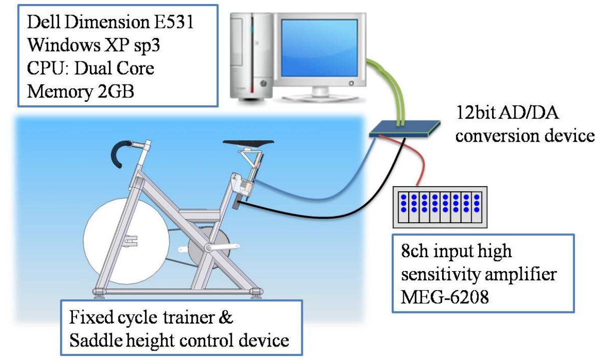

Fig. 4. Schematic of our intelligent saddle height control system

TABLE I

SETTING PARAMETERS OF THE AMPLIFIER

Sampling rate	1kHz
Sensitivity	50μV
High cut	300Hz
Low cut	0.5 Hz
A/D resolution	12bit

B. System structure

1) Mechanical devices: Fig. 4 shows a schematic diagram of the developed system, where a computer running on Windows XP, an instrument device of high sensitive amplifier as an electromyography, and an available fixed cycle trainer. In this cycle trainer, an automated saddle height control device we have developed has been mounted at the top of seat tube. This control device is composed of a DC motor, lack and worm gears, a linear ball bearing, and aluminum plate covers, where the saddle height can be detected with a linear potentiometer via AD conversion board embedded in the computer. The saddle, fizik Arione which is a racing saddle used by lots of professional cyclists, is fixed at the end of the lack gear. Torque of the DC motor is converted to longitudinal force through the combination of lack gear and worm gear. A commonly used PD control method is applied to control the DC motor.

2) Electromyographic instrument: We employed a multi-channel high sensitive amplifier, MEG-6108 as myoelectric instrument produced by Nihon Kohden that is one of major makers of medical electric equipment. Disposable electrode, V-090M3 produced by Nihon Kohden, which is a type of electrically conductive adhesion. Table 1 shows the setting parameters of our measurement system for EMG.

C. Verification experiment

In order to verify the proposed evaluation method using FFT, PCA, and these on-line usage, verification experiments are implemented under the following conditions. The subject is a cyclist who is the coauthor and has over ten years cycling careers and has various road race experiences as Japanese semiprofessional cyclist. Firstly the subject rodes on the fixed cycle trainer and sets the handle and saddle height to match his racing bicycle geometry. The appreciate saddle

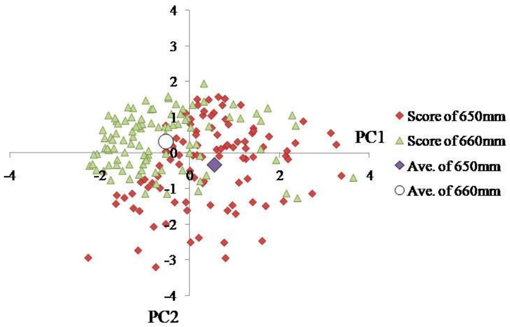

Fig. 5. PCA score of the experiment the saddle height changed from 650mm to 660mm

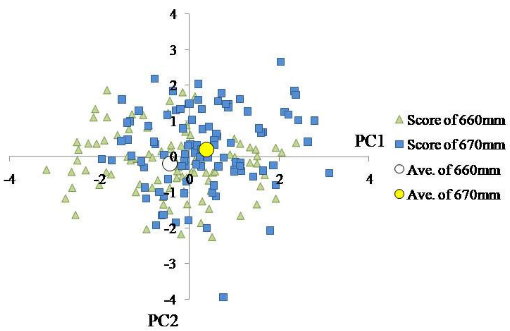

Fig. 6. PCA score of the experiment the saddle height changed from 660mm to 670mm

height the subject has been feeling is 670.0mm. This saddle height is tentatively named as 'Normal' saddle height. 'High' saddle height and 'Very High' saddle height are 10.0mm and 20.0mm higher than Normal height respectively. By the way, 'Low' saddle height and 'Very Low' saddle height are 10.0mm and 20.0mm lower than the Normal height respectively. After patching electrodes on the surface of subject's leg, pedaling exercise begins under 90 revolutions per minute. To film up the pedaling speed of the subject, the computer sounds beep 90 times a minute. In order to survey availability of the numerical evaluation standard proposed in the previous section, the subject firstly pedals on the settings of 'Very low' saddle height. After 100 times of the calculation of muscles' activity, the saddle height goes up to 'Low'. All of PCA score and the averaged scores before and after the change of saddle height are shown in from Fig. 5 to Fig. 8, in which Fig. 6 is the result of that the saddle height changed from 'Low' to 'Normal', Fig. 7 is for the result of that the saddle height changed from 'Normal' to 'High', and Fig. 8 is for the result of the saddle height changed from 'High' to 'Very High'. Due to the difficulty of completely patching the electrodes on the same spot, even using the on-line PCA algorithm, these experiments have to be done concurrently. To avoid the effects of fatigue onto electromyographic signals, adequate rests are taken between the experiments.

For these results, we focused on the relative positional relationship between the averaged score of before and after changing the saddle height. In Fig. 6, the averaged score of

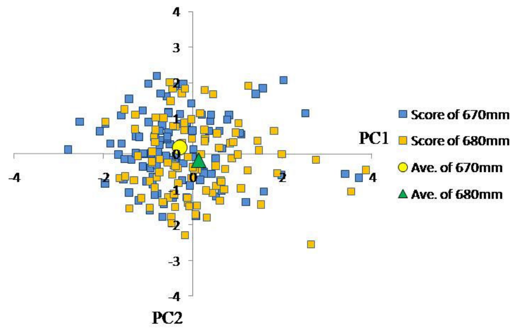

Fig. 7. PCA score of the experiment the saddle height changed from 670mm to 680mm

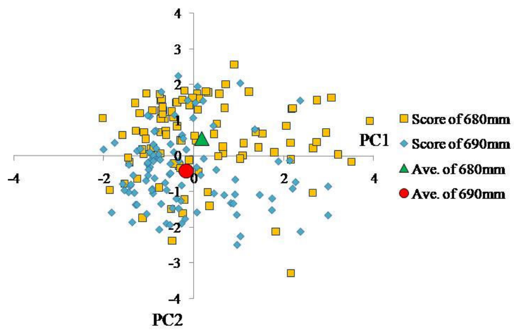

Fig. 8. PCA score of the experiment the saddle height changed from 680mm to 690mm

670mm is positioned in the first quadrant, whereas another one is in the third quadrant. From these results, we derived a scheme of prediction that indicates necessary operation to optimize saddle height as shown in Fig. 9, where the averaged score before the saddle height change is newly defined as the origin point of coordinate. Then, the coordinate point of the averaged score after the saddle height change indicates an operation necessary to make the saddle height more favorable. For example, if the averaged score after the saddle height changed is plotted in Low area in Fig. 9, the saddle height should be made high more than current height.

D. Application of Fuzzy inference to saddle height control

Based on the scheme of prediction we have derived, we would like to estimate more favorable saddle height for the object by using Fuzzy inference. As mentioned in the previous subsection, we firstly set a coordination system at the point of the averaged score before the saddle height changes. The coordinate point of the averaged score after the saddle height change are defined as Gx and Gy respectively. A degree of goodness of Gx and Gy is derived by the membership function shown in Fig. 10. From the scheme of Fig. 9, we built Table II that shows fuzzy rules for saddle height control. The variables from D4 to U4 that have numerical value are obtained from applying Gx and Gy to the membership function described in Fig. 10. Additionally these variables are applied to Table II of fuzzy rules for saddle height control, four evaluation standards as saddle height control level from H3 to L3 are computed, where the

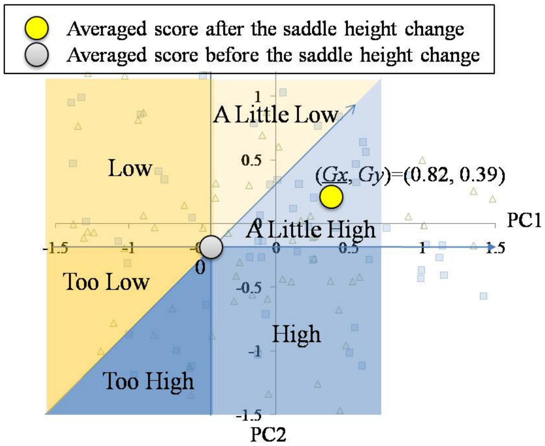

Fig. 9. Scheme of prediction for necessary operation to make saddle height more suitable based on relative positional relationship between before and after saddle height changes

number affixed with H and/or L means the control level, for example, L3 requires to lower the saddle height very much. Table III shows the membership functions, where $G'x$ and $G'y$ are the output value of Table II. Finally a minimax barycentric method makes the fuzzified variables to the amount of saddle height operation.

Fig. 11 shows the schedule of eigenvector calculation for each saddle height. In our planning to implement Fuzzy inference on our system, the calculation of the eigenvector of PCA is running in parallel. The saddle height control starts under the setting of saddle height is low, for example the starting saddle height is 667mm in Fig. 11, and after 100 times calculation of muscular activity the PCA score sheet is complete. The saddle height is changed to 669mm, and then the eigenvector for 667mm is continuously calculated. The next saddle control is executed by using eigenvector for 667mm, where the averaged scores of both of 667mm and 669mm are compared. According to the result of fuzzy

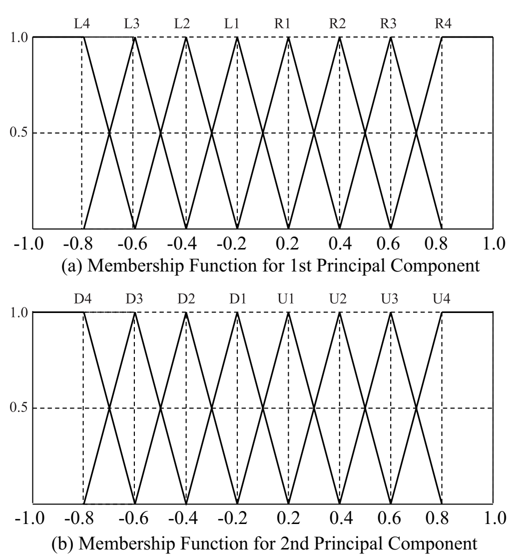

Fig. 10. Membership function for principal component score

TABLE II

FUZZY RULES FOR SADDLE HEIGHT CONTROL

	L4	L3	L2	L1	R1	R2	R3	R4
U4	H2	H2	H2	H2	H1	H1	H1	H1
U3	H2	H2	H2	H2	H1	H1	L1	L1
U2	H2	H2	H2	H2	H1	H1	L1	L1
U1	H2	H2	H2	H2	L1	L1	L1	L1
D1	H2	H3	H1	L1	L2	L2	L2	L2
D2	H3	H3	H1	L1	L2	L2	L2	L2
D3	H3	H3	H1	L1	L3	L3	L3	L3
D4	H3	H3	H1	L1	L3	L3	L3	L3

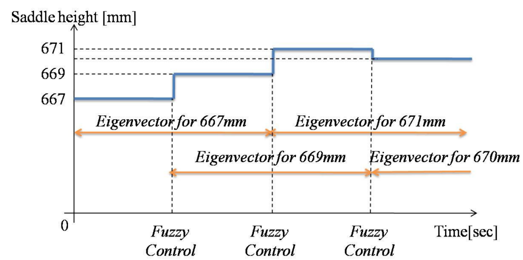

Fig. 11. Schematic diagram of Fuzzy control system based on on-line PCA algorithm

computation, the saddle height is controlled. By repeating the mentioned processes, the saddle height would come close to the optimal height for the subject.

IV. DISCUSSION

This research assumed that an optimized saddle height enables leg muscles to have a well-balanced action under pedaling. After changing saddle height, if the saddle is controlled at favorable height, the averaged PCA score after the saddle height changed relatively moved in the first quadrant of the coordinate system as described in Fig. 9. Then we are considering that to seek the best saddle height is equal to seek the saddle height that is able to intensively plot the scores in the first quadrant of PCA sheet.

The amount of each muscle necessary for pedaling are different, so electromyographic signals increase according to muscle mass. Then we employed the use of a correlation matrix in PCA, in order to evaluate the muscular activity evenly regardless of muscle mass. The feature of this matrix is to analyze based on considering the relationship between all muscles' activity data.

To reveal the real meanings in the field of sports medicine must be effective for the progress of this study. The computer calculates a power spectrum data every 64[msec] and derives muscular activity every 640[msec] in order to consider the muscular fatigue changing during measurement. Wavelet analysis method is better suited for the consideration of the muscular fatigue, because time domain information can be taken account. We are planning to use Wavelet transform to evaluate the effects of muscular fatigue.

The saddle height decision depending on human sensibility is ambiguity. By the basis of this concept we determined to use Fuzzy inference as a way to seek the optimal saddle

TABLE III

THE MEMBERSHIP FUNCTION FOR SADDLE HEIGHT CONTROL

Evaluation standard	Membership function
H3	$\mu_{H3}\left(G'_x, G'_y\right) = W_z - \lvert W_{x1} - \frac{1}{A}G'_x\rvert - \lvert W_{y1} - \frac{1}{A}G'_y\rvert$
H2	$\mu_{H2}\left(G'_x, G'_y\right) = W_z - \lvert W_{x2} - \frac{1}{A}G'_x\rvert - \lvert W_{y2} - \frac{1}{A}G'_y\rvert$
H1	$\mu_{H1}\left(G'_x, G'_y\right) = W_z - \lvert W_{x3} - \frac{1}{A}G'_x\rvert - \lvert W_{y3} - \frac{1}{A}G'_y\rvert$
L1	$\mu_{L1}\left(G'_x, G'_y\right) = W_z - \lvert W_{x4} - \frac{1}{A}G'_x\rvert - \lvert W_{y4} - \frac{1}{A}G'_y\rvert$
L2	$\mu_{L2}\left(G'_x, G'_y\right) = W_z - \lvert W_{x5} - \frac{1}{A}G'_x\rvert - \lvert W_{y5} - \frac{1}{A}G'_y\rvert$
L3	$\mu_{L3}\left(G'_x, G'_y\right) = W_z - \lvert W_{x6} - \frac{1}{A}G'_x\rvert - \lvert W_{y6} - \frac{1}{A}G'_y\rvert$

height for a subject. Repeatability of the experimental result for the subject has been confirmed, so the implementation of fuzzy inference based on PCA score is under constructing. After verification of our proposed method for the object, we would like to correct data from cyclists of varied skills to increase the versatility of our system,

V. CONCLUSIONS

This paper quantitatively evaluated the muscular activities during bicycle exercise by using on-line usage of principal component analysis method. As the result of our experiments, the scheme of predict for necessary operation to make saddle height get up the best saddle height of the subject could be derived. We are constructing the fuzzy control system based on the results we have obtained in this paper.

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