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A CONTROL METHOD FOR WALKING ASSISTANCE ROBOT CONSIDERING EMOTION AND BODY CONDITION

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ABSTRACT

The purpose of this study is to develop a control method for walking assistance robot that enables the elderly to keep positive emotions and maintain high levels of motivation during exercise. In this study, a control method based on emotion recognition and fatigue detection was proposed. We used brainwave and heartbeat signals to train a deep neural network (DNN) model to recognize human emotions. Portable near-infrared spectroscopy (NIRS) was used to detect muscle fatigue. Furthermore, we established a 3D human state model to evaluate the user's emotional and fatigue states. We also performed experiments to evaluate the ability of the control method to improve the effect of walking exercise.

1. INTRODUCTION

The worldwide population aging has brought attention to the physical and mental health of the elderly. The elderly with conditions like stroke face lower quality of life due to the limited moveability and independence in everyday lives. Proper walking exercise is recommended for the elderly to help avoid stroke. However, the elderly is prone to become weary and exhausted when exercising, resulting in a diminished motivation to exercise. Many walking assistance robots for improving human life have been proposed and developed, such as SMA [1] and Curara [2]. We have also developed a small and low-cost walking assistance robot [3, 4]. However, due to negative emotions and muscle fatigue, the elderly may show a decreased willingness for the robot-assist exercise. Besides, the elderly may also experience muscle damage from excessive exercise. To improve the exercise effect of the elderly on the basis of preventing muscle damage, we proposed a control method based on emotion recognition and fatigue detection. Therefore, the robot can guide users to exercise with positive emotions and high motivations. The process of the control method is as follows (Fig. 1): (1) Recognize the user's state based on 3D human state model (2 emotional dimensions and 1 fatigue dimension); (2) Make appreciate walking mode according to the human's current state; (3) Change walking mode of the robot based on the proposed walking control strategy; (4) Maintain positive emotion and good physical condition.

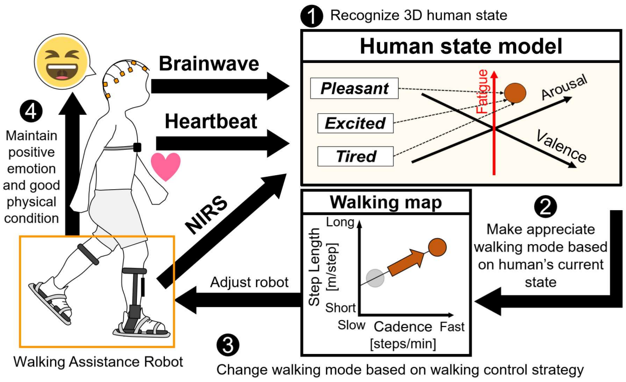


Fig. 1 Process of control method.

2. EMOTION RECOGNITION

To avoid the long-term negative emotion of the user during exercise and maintain their exercise motivation, the robot needs to recognize the user's emotions. Facial expression collection and physiological signal analysis are common methods for emotion recognition. However, the human can hide their true emotions through fake expressions, which can affect the accuracy of recognition. Therefore, we chose the emotion recognition method based on physiological signals analysis. In this study, we simplified the human emotion recognition into a 2D emotion model: arousal (including unexcited, normal, and excited) and valence (including unpleasant, normal, and pleasant). We developed a DNN-based human emotion recognition system [5]. For the neural network training, we collected brainwave and heartbeat data from 20 subjects under specific emotions using electroencephalograph (EEG) and heartbeat sensor.

For the arousal state classifier, we selected Alpha, Low-Beta, High-Beta and Gamma as features from brainwave, LF/HF (LF: Low Frequency/HF: High Frequency) ratio and heart rate (HR) as features from heartbeat data. For the valence classifier, we selected Alpha, Low-Beta, High-Beta and Gamma as features. We will continue to improve this emotion recognition system to improve its reliability and accuracy.

3. FATIGUE DETECTION

To prevent muscle damage caused by excessive fatigue, the robot needs to detect human fatigue state. Calculating the mean power frequency (f_{MPF}) of the electromyography (EMG) signal can evaluate muscle fatigue. Generally, the decrease in f_{MPF} means muscle fatigue. The calculation of f_{MPF} can be expressed by Equation (1).

$$f_{MPF} = \frac{\int_0^{f_0} fP(f)df}{\int_0^{f_0} P(f)df} \quad (1)$$

f_0 represents the sampling frequency, and $P(f)$ represents the power spectral density function of EMG data. Since physiological signals need to be detected during human walking, it is important to use portable sensors for detection. EMG-based detection requires users to wear bulky equipment and sticky sensors that are difficult to install quickly. Considering the portability and ease of use, we used NIRS to detect the amount of oxygenated hemoglobin (C_{oxy}) and deoxygenated hemoglobin (C_{deoxy}) in muscle tissue. Previous research has shown that C_{oxy} and C_{deoxy} cross over when muscle fatigue occurs [4].

To develop the fatigue detection-based control strategy, we conducted experiments to explore the relationship between NIRS data (C_{oxy} and C_{deoxy}) and muscle fatigue. Since dorsiflexion and plantarflexion of foot are driven by tibialis anterior (TA) muscle, in the experiment, we attached the EMG sensor and the NIRS sensor to the subjects' TA muscles to collect data. Six subjects, aged between 23 and 26 years, were invited to the experiment. Subjects were instructed to walk as fast as possible with a stable cadence on the treadmill until exhaustion. Then, all subjects felt exhausted within/after 1 hour. Finally, we compared the NIRS data with the f_{MPF} of EMG data.

Figure 2 shows one of the samples of the experimental data, where several drops in f_{MPF} occurred at around 600s, 1250s, 1950s, 2550s, and 3500s, respectively. And during these periods, C_{oxy} and C_{deoxy} crossed and then separated. To better represent the fatigue state, we adopt a value C_{minus} [6], which is defined by Equation (2).

$$C_{minus} = C_{oxy} - C_{deoxy} \quad (2)$$

Therefore, we proposed a process to detect muscle fatigue during walking (Fig. 3): (1) Before the first fatigue, C_{oxy} is smaller than C_{deoxy}; (2) After the first fatigue, C_{oxy} is larger than C_{deoxy}; (3) When fatigue occurs again after the first fatigue, C_{oxy} decreases while C_{deoxy} increases, and they are crossed or tend to get closed; (4) When human recovers from fatigue, C_{oxy} increases while C_{deoxy} decreases.

4. WALKING CONTROL STRATEGY

Based on the 3D human state model, we proposed the walking strategy as follows:

(1) Warm-up stage: when the user starts exercising, C_{oxy} increases and C_{deoxy} decreases because the muscle needs oxygen to activate;

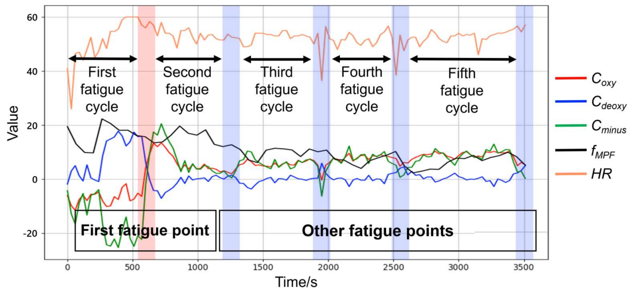


Fig. 2 Sample of experiment result.

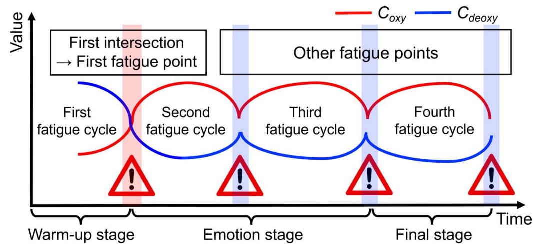
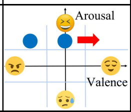
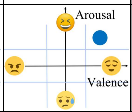
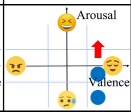
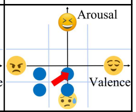
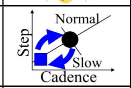
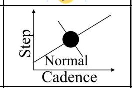
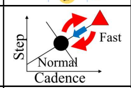
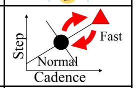


Fig. 3 Detection of fatigue based on NIRS.

Table 1 Walking modes for walking control strategy

Walking mode	Repeatedly Slow	Normal	Repeatedly Fast (-)	Repeatedly Fast (+)
Target emotion	Pleasant	Maintain user's state	Excited	Pleasant and Excited
Emotion map				
Gait map				
Cadence [steps/min]	64	73	83	93
Step length [cm/step]	38.4	43.8	49.8	55.8

(2) Emotion stage: before reaching the final stage, the robot needs to stimulate the user's exercise motivation as much as possible;

(3) Final stage: to prevent muscle damage caused by repeated fatigue, when the fatigue occurs 2 or 3 times, users should stop muscle activity (stop walking).

For the emotion stage, we have found the relationship between emotion and walking mode: (a) When users are walking repeatedly fast, they may be more excited; (b) When users are walking repeatedly slow, they may be more pleasant; (c) When users are walking with slower cadence and longer step length, or with faster cadence and shorter step length, they may be less excited.

Therefore, to let users reach pleasure and excitement during walking, we designed four walking modes for the walking control strategy by setting different cadences and step lengths (Table 1): (a) Repeatedly Slow: slower cadence and shorter step length than Normal. (b) Normal: ordinary cadence and step length; (c) Repeatedly Fast (-): slower cadence and shorter step length than Repeatedly

Fast (+) but faster than Normal; (d) Repeatedly Fast (+): fastest cadence and longest step length. To quantify each walking mode, we measured the cadence and step length and calculate the average in different walking modes from 7 able-bodied people.

5. EVALUATION EXPERIMENT

5.1 Experiment protocol

We proposed a walking experiment to evaluate the effectiveness of the proposed control system. Three subjects, aged between 24 and 28 years, were invited to the experiment. They were required to wear EEG, heartbeat, and NIRS sensors to assess their emotion and fatigue state. The process of the experiment is as follows:

(a) On the first day, the subjects were asked to walk without the robot at a normal speed, until the NIRS data indicated 3 fatigue points;

(b) After a day of rest, on the third day, the subjects were asked to wear the robot without the walking control strategy, and walk at a normal speed, until the NIRS data indicated 3 fatigue points;

(c) After a day of rest, on the fifth day, subjects were asked to wear the robot with the walking control strategy and walk, until the NIRS data indicated 3 fatigue points.

Finally, we evaluated the effectiveness of the walking assistance control method by comparing walking time and walking distance from the experiment.

5.2 Walking time comparison

The result for walking time is shown in Fig. 4. In experiment (a) and (b), the subjects walked at the same and fixed speed. In most cases, subjects' walking time increased by wearing the robot with the walking control strategy. By implementing the control strategy, two subjects walked 200s longer and one subject walked 90s

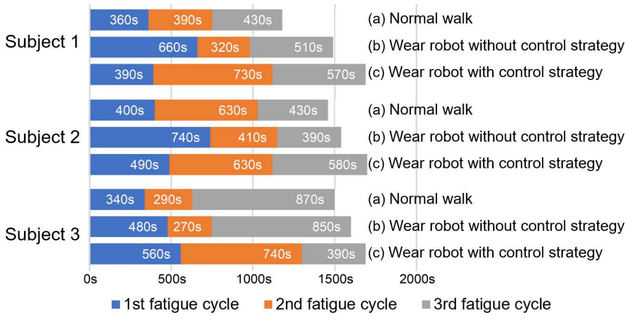


Fig. 4 Walking time comparison in 3 subjects.

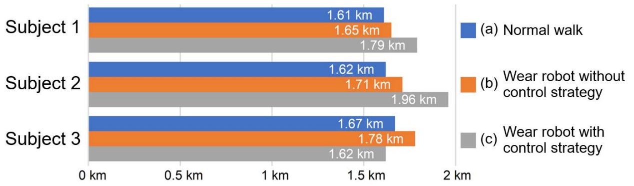


Fig. 5 Walking distance comparison in 3 subjects.

longer, the experiment result shows that the system can delay fatigue time by about 24%.

5.3 Walking distance comparison

Due to the implementation of the walking control strategy, the users' walking speed has changed. Therefore, we compared the walking distance when users reach to fatigue point. Fig. 5 shows the walking distance for 3 subjects in each experiment. Subjects 1 and 2 walked longer distances when they walked with the robot and the control strategy, the experiment result shows that the system can increase walking distance by about 16%. Subject 3 had a longer walking distance when they walked with the robot and without the control strategy, but after implementing the control strategy, the walking distance decreased. The possible reason is that he walked longer than other subjects in the second fatigue cycle, resulting in too much physical exertion.

6. CONCLUSION

In this study, we proposed a 3D human state model based on human emotion recognition and muscle fatigue detection. And then, we designed a control method for the walking assistance robot based on the 3D model. Finally, we verified the effectiveness of the control method through the experiment. The system can improve the user's exercise motivation to a certain extent and prevent muscle damage. In the future study, we will conduct more evaluation experiments and improve the accuracy and effectiveness of the control method.

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