Study on Walking Assistance Considering Emotion Evaluation with a Device of Compact Design

Jyun-Rong ZHUANG

June 2020

Waseda University Doctoral Dissertation

Study on Walking Assistance Considering Emotion Evaluation with a Device of Compact Design

Jyun-Rong ZHUANG

Graduate School of Information, Production and Systems

Waseda University

June 2020

Abstract

With an increase in the aging population worldwide, the issues of the promotion in exercise are gradually concerned to prevent a stroke for the elderly. Proper walking exercise is a good way for the prevention of a stroke in the elderly. However, long-term exercise involves much tired, impatient, and discomfort which causes the elderly hard to continue it. To keep motivation during exercise is thus a vital issue. The main purpose of this dissertation is to conduct a feasibility study on walking assistance considering emotion evaluation, which can provide the elderly to synchronously gain the assistance of mental and physical further maintaining the motivation during exercise. To achieve the purpose, a hybrid system integrating an emotion evaluation and walking assistance is proposed. The goal is to make the elderly gain gait assistance with positive emotions (1st quadrant of 2D emotion map (x-axis: pleasant/ y-axis: arousal). In the aspect of walking assistance, to reach the minimum load during walking assistance for the elderly, a compact ankle-assist device is proposed. However, the device easily encounters unexpected loads that lead to a gear broken in the motor. To avoid breakage, a compact torque limiter is designed in a gear of motor. It keeps the same size and weight as the original gear. The torque and durability tests verified the effectiveness of torque limiter. The results showed using NBR rubber in the torque limiter can reach the rated torque (4 [Nm](60% of the patient assisted torque)) of motor and respond well to the service life at least continuous accidents of 300 times (1 exercise/ day for 30 [min] encounters 1 accident. Can use for 10 months.). 3 subjects (23-27 years old) had walked for 1 hour while using the device. The results proved it can improve the dorsiflexion motion from 15 to 28 [deg] (+46%), the kicking timing from 75% to 70% (-5%), and the step length from 0.68 to 0.75 [m] (+9%) (in comparison to without wearing the device and with wearing the device). The foot trajectories showed forefoot can be raised by using the device. The device proved it can promote exercise. Furthermore, in the aspect of emotion evaluation, to recognize emotions more accurately, a 2D emotion recognition system using multiple physiological signals (heart rate variability, muscle activities, and brainwave) is proposed. By matching physiological data and questionnaire (20 subjects, 21-27 years old), the training set is built then to create a deep neural network (DNN) models (total 5 layers with 3 hidden layers) as an emotion recognition system that can recognize the nine emotion states. 17 parameters (based on high contribution value) a

. This DNN validated its superior accuracy in comparison with other algorithms (SVM, Naïve Bayes, and K-means). To assess the efficiency, the results verified the feasibility in real emotion evaluation (t / questionnaire]). By integrating emotion recognition and assistive walking device, an assistance method for the promotion of emotional state during walking is proposed. 7 subjects were required to walk from current gait to four gaits (high cadence (C)-long step length (S), low C-short S, high C-short S, and low C-long S) based on personal preferred walking ratio (y=ax)of a 2D walking map (x-axis: C, y-axis: S). From the vector variation of emotion and walking, the results proved walking changes can decide the direction of emotion changes. A hybrid system is developed. To raise the assistive effect, repeated and cycled walking are proposed as strategies to promote emotion. 3 subjects (20-generation years old) conducted the experiment. By questionnaire results (total points:1-7; center point: 4), compared to with tuning and without tuning while using device, the results proved when using repeated walking: pleasant promoted from 2.9 to 4.2 [point] (+18%), and arousal promoted from 2.6 to 4.1 [point] (+22%). When using cycled walking: pleasant promoted from 2.9 to 4.1 [point] (+18%), and arousal promoted from 2.6 to 3.7 [point] (+15%). After that, a control strategy to promote and maintain the positive emotion was proposed. Based on emotion evaluation, the assistive device tuned the target condition (target walking cycle (reciprocal of cadence) and target ankle angle variation (relationship with step length)) to users walking further generated new emotion. The control strategy shows as follows: When users feel unpleasant or unexcited, their emotions would be activated to the 1st quadrant of 2D map. However, the fatigue would occur owing to the long time located at high arousal state. Thus, users' emotions would be activated to the 4th quadrant (relax and calm) of 2D map. From the evaluation of initial emotion and final emotion (10 min), averaged results of pleasure promoted from 3.1 to 5.5 [point] (+33%), and arousal promoted from 3.3 to 4.2 [point] (+13%). The results validate the effectiveness of this control strategy. In conclusion, by using this system, the elderly can satisfy their mood with a physical device to reach the goal of exercise. They can thus gain a high sense of achievement further keep motivation and promote confidence in real life without other people's help.

Keywords— Assistive walking device, Emotion recognition, Emotion-walking relationship, Emotion-walking controlled system, Promote emotion, Maintain motivation

Contents

List of Figures

List of Tables

List of Symbols

A	The parameter of ankle angle variation- step length equation
A_1	The parameter of ankle angle variation- step length equation, at 0% to 10%
A_2	The parameter of ankle angle variation- step length equation, at 10% to 40%
A_3	The parameter of ankle angle variation- step length equation, at 40% to 60%
A_4	The parameter of ankle angle variation- step length equation, at 60% to 85%
A_5	The parameter of ankle angle variation- step length equation, at 85% to 100%
A_c	The circular contact surface area
A_g	The projected area of the groove
A_{side}	The area of the lateral side
B	The parameter of ankle angle variation- step length equation
B_1	The parameter of ankle angle variation- step length equation, at 0% to 10%
B_2	The parameter of ankle angle variation- step length equation, at 10% to 40%
B_3	The parameter of ankle angle variation- step length equation, at 40% to 60%
B_4	The parameter of ankle angle variation- step length equation, at 60% to 85%
B_5	The parameter of ankle angle variation- step length equation, at 85% to 100%
B_p	Band power of brain wave [$\mu V^2/Hz$]
C	Cadence [steps/min]
C_N	Initial target cadence [steps/min]
C_T	Target Cadence [steps/min]
$CondEntropy(E\|T)$	Conditional entropy of the feature T on set E.
D	External diameter of torque limiter
E	Set E
$Entropy(E)$	Entropy of set E
F_S	The local shear force of the groove
F_{bw}	The brainwave value in the frequency domain
F_{hrv}	The HRV value in the frequency domain
$Gain(E,T)$	Information gain of feature T to set E
$Gainratio(E,T)$	Information gain ratio of feature T to set E
I	Emotional class (for one emotion dimensional classifier is 3 classes)
$IntI(E,T)$	Int
)	The marginal probability of observing I
$P(Z)$	The marginal probability of observing Z

$P(I\|Z)$	Conditional probability : the likelihood of event I occurring given that Z is true
$P(Z\|I)$	Conditional probability : the likelihood of event Z occurring given that I is true
S	Step length [m]
S_T	Target step length [m]
S_N	Step length in normal walking [m]
T	Set T
V	Walking speed [m/sec]
W_T	Target walking cycle [sec]
$W_{T_{initial}}$	Initial Target walking cycle [sec]
$W_{T_{new}}$	New target walking cycle [sec]
X	The value of EMG signals
X_{ij}	Input value of signal space
Y	Overall predicted output
Z	Physiological features using in Naive Bayesian
a	The numbers of sample datasets
b	Bias which is one of parameters in DNN
c	The numbers of classes
d	Internal diameter of torque limiter
e	The variables in set E
i	The numbers of sample
i_i	The emotion score using in the support vector machine
j	The numbers of features
k	The numbers of cluster
l	The numbers of sample in signal space
m	Weighting in the DNN, it is one of parameters in DNN
n	The numbers of grooves
p_T	Target Walking phase[%]
$p_{T_{current}}$	Current target Walking phase[%]
$p_{T_{next}}$	Next target Walking phase[%]
r	An element of the radius
r_m	The equivalent radius
s	The distance from any point to the line equation
v	The numbers of sets ($v \in \mathbb{R}$ and $v > 0$)
t	The thickness of the material
w	Parameter of linear equation using in the support vector machine
x_{ij}	Input value of unit space
y_{ij}	Output value of unit space
(x_i, y_i)	The position of walking trajectory
z_i	Arbitrary data; Physiological features using in Naive Bayesian and k-means method
α_B	Alpha wave
α_d	Tuning parameter for target ankle angle variation
β	The sensitivity of the output concerning the input data
β_B	Beta wave
β_d	Tuning parameter for target walking cycle
γ_B	Gamma wave
θ_B	Theta wave
θ_{fast}	Ankle angle when fast walking

θ_{slow}	Ankle angle when slow walking
θ_{normal}	Ankle angle when normal walking
θ_N	Initial target ankle angle [deg]
$\theta_{N_{0\%}}$	Initial target ankle angle [deg] at walking phase 10%
$\theta_{N_{40\%}}$	Initial target ankle angle [deg] at walking phase 40%
$\theta_{N_{60\%}}$	Initial target ankle angle [deg] at walking phase 60%
$\theta_{N_{85\%}}$	Initial target ankle angle [deg] at walking phase 85%
$\theta_{N_{100\%}}$	Initial target ankle angle [deg] at walking phase 100%
θ_T	Target ankle angle [deg]
$\theta_{T_{current}}$	Current target ankle angle [deg]
$\theta_{T_{next}}$	Next target ankle angle [deg]
$\theta_{T_{new}}$	New target ankle angle [deg]
$\theta_{T_{0\%}}$	Target ankle angle [deg] at walking phase 10%
$\theta_{T_{40\%}}$	Target ankle angle [deg] at walking phase 40%
$\theta_{T_{60\%}}$	Target ankle angle [deg] at walking phase 60%
$\theta_{T_{85\%}}$	Target ankle angle [deg] at walking phase 85%
$\theta_{T_{100\%}}$	Target ankle angle [deg] at walking phase 100%
θ_{dorsi}	Dorsiflexion motion angle
θ_{dorsi_N}	Initial dorsiflexion motion angle
θ_{dorsi_T}	Target dorsiflexion motion angle
θ_{var}	Ankle variation angle
θ_{var_T}	Target ankle variation angle
θ_{var_N}	Initial ankle variation angle
ψ_i	Current value which using in the gradient descent algorithm
ψ_{i+1}	Next value which using in the gradient descent algorithm
$\dot{\theta}_T$	Target ankle's angular velocity [deg/sec]
$\dot{\theta}_{T_{new}}$	New target ankle's angular velocity [deg/sec]
$\dot{\theta}_M$	Motor's input angular velocity [deg/sec]
$\dot{\theta}_{M_{new}}$	New Motor's input angular velocity [deg/sec]
$\dot{\theta}_{MO}$	Motor's output angular velocity [deg/sec]
$\dot{\theta}_{MO_{new}}$	New Motor's output angular velocity [deg/sec]
η	S/N ratio (Signal-to-Noise ratio)
ζ	Learning rate
μ	Friction coefficient
μ_c	Center point of cluster
τ_{max}	Maximum Torque of motor
τ_{rated}	Rated Torque of motor
$\tau_{w/o}$	The delivered frictional torque generated by the without grooves type
τ_w	The delivered frictional torque generated by the with grooves type
σ_{a_i}	Probability distribution of the actual class
σ_i	Probability distribution of the predicted class

Chapter 1

Introduction

1.1 Background

1.1.1 The Issue of Aging Population

According to the statistics of World Population Prospects, the percentage of elderly within the total population has increased [1-3], as shown in Fig.1.1. Especially, Japan will face the serious issue of the aging population (over 35 [%]) in 2050, as shown in Fig. 1.2 [4-5]. With the issue of the aging population, stroke has also increased. The elderly are very easy to get a stroke. Aging is still a common cause of death and disability in the elderly [6][7]. Aging causes muscle strength degradation, cardiovascular and metabolic disease incidence increasing, which influences on the reduction of physical activity. The elderly people are thus being bedridden easily then leading to stroke. The issue of prevention of stroke in the elderly is necessary to study. In spite of some therapeutic medicines being able to suppress the risk of stroke diseases, physical therapy is not negligible. The demand for wearable assistive devices thus corresponding increases. Additionally, from the viewpoint of the mental condition of the elderly, it is necessary to deeply investigate. Thus, not only studies the physical assistance but also the mental assistance must be considered.

According to the social investigation, almost one-fourth of old men and one-fifth of old women may have a stroke [8]. In recent years, the number of people with hemiplegia in middle-aged and elderly patients has increased due to cardiovascular and cerebrovascular diseases, and the patients become younger and younger. At the same time, due to the rapid growth of transportation tools, the number of people suffering from nerve damage or limb damage due to traffic accidents is also increasing. It is estimated that 4.5 million people worldwide die from stroke each year and more than 9 million people get a stroke. The total incidence of stroke is about 2-2.5 per 1,000 population. The recurrence rate over 5 years is 15-40 [%]. It is estimated that by 2023, the number of patients will increase by about 30 [%] compared to 1983. Stroke is the

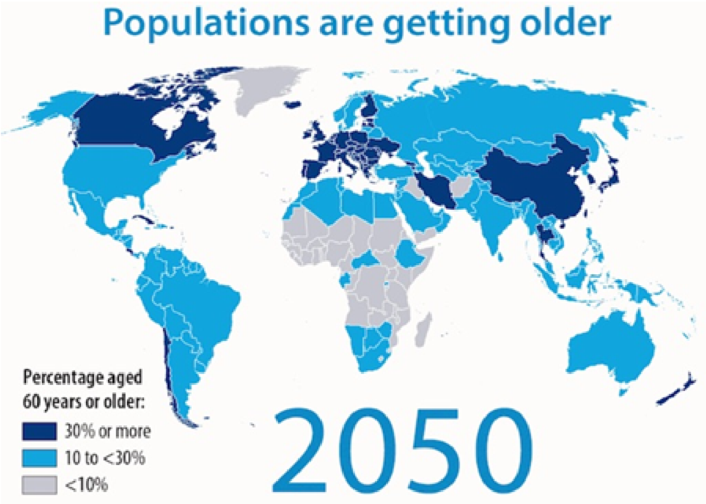


Figure 1.1. Population are getting older in the world [3].

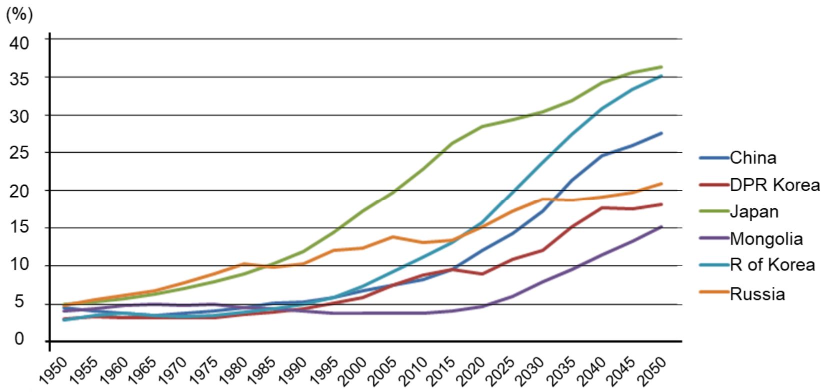


Figure 1.2. Percentage of elderly (over 65-year-old) within the total population in their country [4].

leading cause of adult disability. The total prevalence rate is about five thousandths. After one year of getting a stroke, 65 [%] of survivors can live independently. For these kinds of people, adequate exercise is considered helpful for improve physical conditions. Through repetitive training and a variety of tasks and feedback exercises, muscle strength can be obtained [9-10]. If the people appropriate use an assistive device to do exercise, they can receive the gait training and simultaneously stimulate the neural circuits of the brain, then avoiding getting a stroke.

Besides, for post-stroked people, it is also very useful. Medical therapy and clinical medicine prove that except early surgical treatment and necessary medical treatment, correct and scientific rehabilitation training also plays an important role in the recovery and improvement of limb motor function. Proper exercise with the assistive device is very helpful for retaining the body condition during rehabilitation. Therefore, the promotion of exercise is an important topic for elderly and post-stroke patients.

The underlying goal of post-stroke rehabilitation and the elderly exercise are to improve body function, prevent complications, improve activity daily living (ADL), and ultimately return patients and the elderly to their family and the society. Standardized procedures and treatment options are of great significance in reducing the disability rate of acute cerebrovascular disease and improving the quality of life of patients.

Early rehabilitation training and exercise not only maintain joint mobility and prevent joint contracture but also significantly improves the ultimate recovery of motor function. The traditional rehabilitation therapy method usually relies on the physiotherapist to manually drive the patient's limbs for passive training. The training strategy is relatively simple. At the same time, during the training process, the force applied to the affected limb and track of the affected limb is difficult to maintain. Moreover, this type of rehabilitation requires physical therapists to perform stronger training work, it is thus often difficult for patients to get adequate strength and effect of rehabilitation [11].

With the rapid development of science and technology, some existing problems have gradually emerged. First, in most cases, a physical therapist can only exercise training on one patient at the same time, which is inefficiency. Because of the physical therapist's own reasons (The treatment effect depends on the experience and level of the physiotherapist), it may not be possible to ensure that the patient receives sufficient training intensity. Secondly, it is impossible to accurately control and record the movement speed, trajectory, and intensity of the training parameters, which is not conducive to the determination and improvement of the treatment plan. It is difficult to objectively quantify the evaluation index, which is not conducive to provide enough effect of treatment and training for patients and the elderly. It is also unable to provide real-time and intuitive feedback information to the patients. The training process is not attractive, the patients are passively receiving treatment, and the initiative to participate in the treatment is not enough. As mention above, the case described the post-stroke patients' condition when performing rehabilitation. Similarly, the elderly also face a very closely issue while doing exercise (such as do exercise alone is hard to keep the same strength level meanwhile easily lose motivation). Therefore, it is imperative to develop a wider range of training methods and further improve rehabilitation and exercise efficiency to solve patients' and elderly's motor dysfunction.

Compared with the traditional artificial rehabilitation training mode, the assistive devices d It has many advantages: (1) The device is more suitable for performing long and simple repeated movements, which can ensure the strength, effect, and precision of rehabilitation training, (2) Generally, the assistive device has programmable ability to provide individualized training of different strengths and modes according to the degree of injury and rehabilitation of the patient, (3) Rehabilitation devices usually integrate a variety of sensors and have powerful information processing capabilities. They can effectively monitor and record data such as human kinematics and physiology during the entire rehabilitation process. By giving real-time feedback on the patient's progress and making quantitative evaluation, it can provide a basis for doctors to improve rehabilitation programs [12-13].

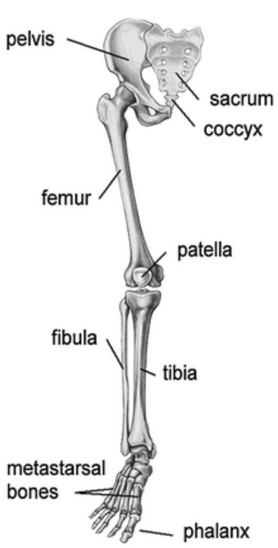


Figure 1.3. Anatomy of the lower limbs [14].

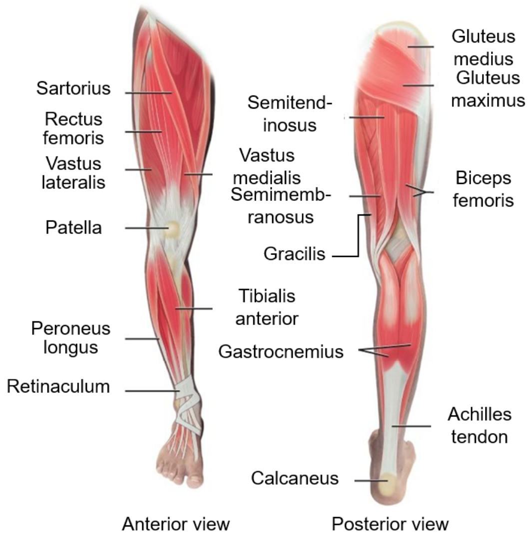


Figure 1.4. Muscle of the lower limbs [15].

Figures 1.3 and 1.4 show the skeleton structure of the lower limbs of the human body [14-15]. The pelvic bones are free of the lower extremity bones including the femur of the thigh, the tibia and fat bone of the small leg, and the phalanges of the foot. The various movements of the lower limbs are the result of the synthesis of these parts' relative motion. The knee joint is the largest and most complex joint in the human body. It is located between the two largest levers of the body, the femur, and the tibia. It consists of the femur, tibia, and fibula. It can make the calf flexion and extension movement, in which the tibia moves up and down during knee flexion and extension to maintain the stability of flexion and extension movement.

The following content is the analysis of the range of the lower leg's joints. The hip joint is a multi-axial joint that can achieve flexion, extension, rotation, and circular motion, which is determined by the hip joint structure. The hip joint is the connection between the hip bone and the femur. The femoral head is deeply embedded in the acetabulum of the hip bone and wraps around the femoral head nearly 2/3. This structure is beneficial to improve the support force of the lower limb but limits the range of motion. Therefore, the range of motion is small. The outer part of the hip has a thick joint capsule, which makes the ligament tenacious and strong. The stability of the hip joint is strengthened, which also affects flexibility. The function of this structure is to keep vertical walking to the ground and pass the upper body weight to the lower limb. When walking upright, according to the definition of the anatomical coordinate plane, the angular range of the hip joint in the sagittal plane is from 0 [deg] to 30 [deg], and the angle range of the adduction changes from 0 [deg] to 25 [deg]. The knee joint is connected to the thigh and calf. It is composed of the femur, fibula, and tibia. It is the largest, most flexible, and complex joint in the human body. The knee joint has a certain rotation activity. It is a non-strict type of hinge joint. The main motion is flexion and extension (angle varies from 0 [deg] to 135 [deg]). It can also rotate along the longitudinal axis. The flexion and extension axis of the knee joint is not fixed, and it is placed in a hook-like movement about the ankle [16].

Especially, the ankle joint is the distal joint of the lower extremity, which controls the movement of the foot relative to the lower leg, as shown in Fig. 1.5. It is important for keeping balance. The basic movements are dorsiflexion, plantarflexion, abduction, and adduction. The range of ankle's movement range is from 20 [deg] to -50 [deg].

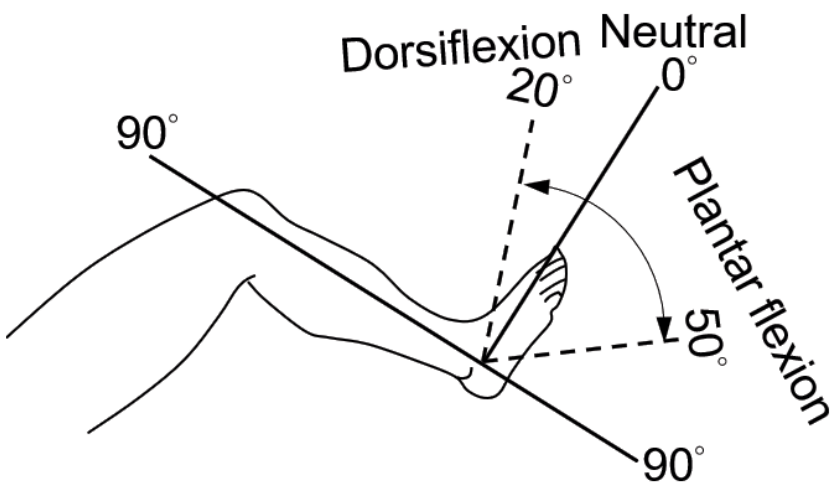


Figure 1.5. Range of ankle joint of human [16].

The lower extremity exoskeleton rehabilitation robot is the physical interface of human-computer interaction in the process of rehabilitation training. The comfort and practicability in the process of use should be the primary consideration. In order to design the exoskeleton robot that the patient wears comfortably, the anthropomorphism of the structure is very important [50]. Therefore, before the mechanical structure design of the exoskeleton robot and assistive device, the physiological structure and movement mechanism of the lower limbs should be studied deeply. In addition, in order to enable the robot to simulate the movements of the rehabilitation therapist, it is necessary to first understand the methods and procedures for walking motion of people.

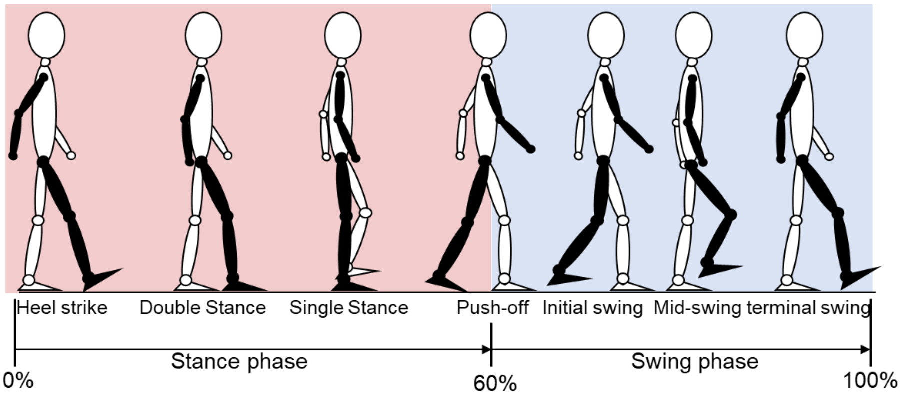


Figure 1.6. Normal walking cycle in health adults.

Walking is a basic but complex motion in humans. It involves the nervous system, the muscular system, skeletal system, and the cardiorespiratory system. Walking behavior is extremely affected by age, personality, and emotion. Figure 1.6 shows the completed walking cycles which began and ended with heel strike of the same foot. The walking cycle mainly is constituted by the stance phase and swing phase. The stance phase constitutes about 60 [%] (starts at heel strike; ends at push-off) in the walking cycle. The swing phase constitutes around 40 [%] (starts at toe-off; ends at heel strike) in the walking cycle [17]. During the whole walking cycle, initially, one-foot hits at the ground and rotates a little angle to prevent tripping. Until the foot contacts the ground again, one gait is finished.

Walking mainly reflected in the advancement, turning or retreating of the human body. The human walking process relies on the bones, muscles, and the nervous system that controls the muscles, so the lower limbs of the human body are a highly complex automatic adjustment system. In this system, the bone is the lever of the movement, the joint is used for the movement,

t

-related natural decline, which has begun in middle age and increases the risk of decline in physiological function in later life [20]. Moreover, the physical system suffers varying degrees of pain in different parts of the body. This results in a reduction of the functional reserve, lung capacity, capillary blood supply, and muscle mass [21]. Because the elderly are sedentary, lack of exercise leads to decreased strength, endurance, and flexibility, which leads to loss of functional health [22]. "Using it or losing it" has proven to be a key rule for maintaining the independence of the elderly [23], as shown in Fig. 1.8 [24].

Owing to the described above, the elderly may use the protective gait to walk. For the prevention of falling, the gait of the elderly becomes shorter step length, slower walking speed, and lower feet height, in comparison to healthy adults. The elderly therefore easily exhibited the disorder gait in daily life. Additionally, the reduction of muscle strength with age, especially, during movement, the dorsiflexion motion can be driven only by the tibialis anterior (TA) m - cle. Therefore, TA muscle is very easy to fatigue; whereby, foot drop will happen due to TA muscle weakness, which increases the falling risk. Additionally, individuals with the diseases of stroke and cerebral palsy are also easy to occur in foot drop (such as hemiplegic patients). When individuals happen foot drop, they cannot lift their forefoot in walking. This causes them to slap and drag their forefoot on the ground every step. This gait abnormality may lead to unexpected accidents (such as stumbling and slipping) in daily life. Figure 1.7 shows the gait abnormality of the hemiplegic patients and the ideal gait of an able-bodied person. Accordingly, the assistance of TA muscle should be considered for the elderly and patients. To give the assistance of the lower limbs, the assistive device has been proposed to resolve this issue.

Additionally, from Chiu's research of or elderly people, more than 45 [%] had difficulty in movement on stairs due to the poor balance and movement disorder [18]. Compared with young people, the elderly have less control of their joint and lacks flexibility during the stair walking transition. With the aging of the elderly, their muscle strength and walking speed decreases compared with young people that increase the risk of falls [19]. Thus, elderly people need an assistive device to support their motion and protect them from falls.

Studying human-robotic interaction (HRI) has been received attention in recent years [25]. Robots have been extended to assist people further improved their life. As an assistive device, it

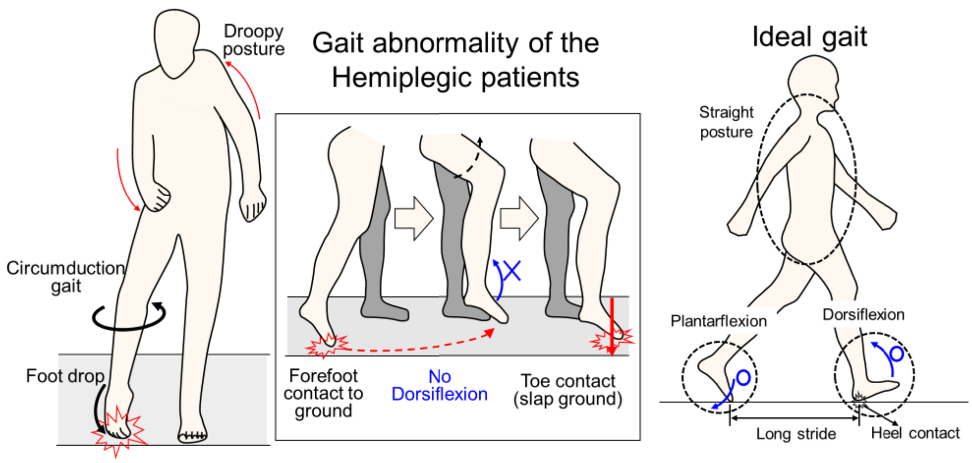


Figure 1.7. Gait abnormality of the hemiplegic patients and ideal gait of able-bodied person.

is very important to meet the needs of the user, and only then will the user have a better healing effect. Since the user is initially unfamiliar with how to properly use an auxiliary device, the user will think that he or she is not getting help or feel uncomfortable. Therefore, the design of the assistive device also needs to consider the user's mood to ensure the user's motivation. Only when there is a positive emotion can the user get the best assistive effect.

At present, the emotional research of the elderly mainly focuses on the common problems caused by the physiological changes, that is, the decline of body functions. From the perspective of humanity, human beings have both natural and social attributes. The aging of the elderly is not only a declined process of biomedicalization but a process of multidimensional function, including physiological, psychological, and social life changes. Therefore, we should explore the emotional needs of the elderly from different perspectives. With the increase of age, the perception ability of the elderly is reduced due to aging or pathological reasons, such as gradually decline in vision and hearing, decreased sensory ability, and reduced ability to adapt to the environment. In order to enhance the safety of the elderly, the primary task of design is to meet the physiological and safety needs of the elderly. The decline in the physiological function of the elderly leads to a change in mental state. It is reflected in loneliness, anxiety, and inferiority. When the elderly are in a negative psychological mood, loss of confidence, and courage will accelerate aging. In fact, although the perception of the elderly has declined but not completely lost, the elderly products should arouse the positive emotions of the elderly through improved design. The emotional satisfaction of being convenient, confident, and happy in the experience is the trend of the situation. As the life circle suddenly becomes smaller after retirement, the

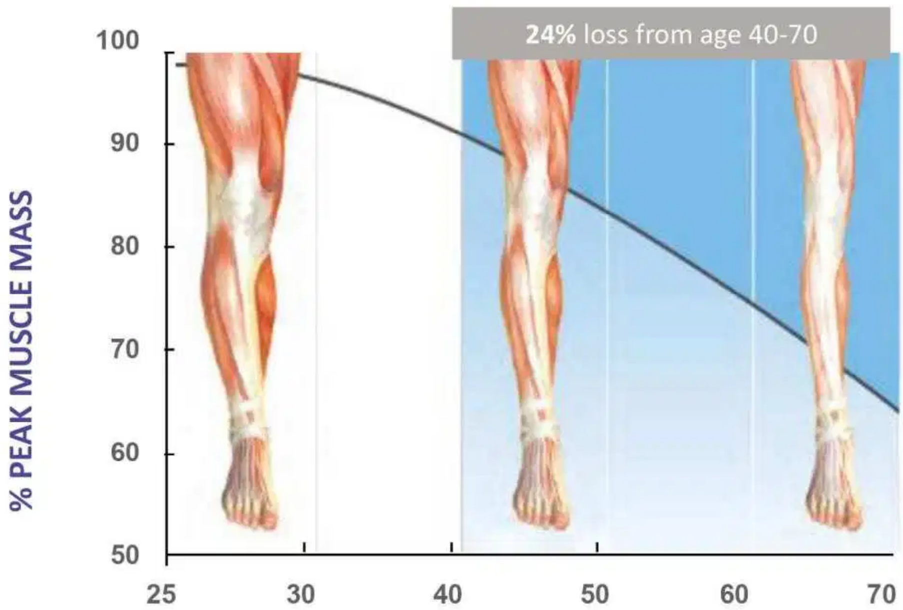


Figure 1.8. Loss of muscle length with aging [24].

change in social status makes the elderly feel a huge drop. Therefore, the elderly tend to be busy to ease the feeling of being abandoned by society. In this context, the elderly eager to live independently, do not want to trouble the children and choose to support themselves, even if the elderly are inconvenient.

Service devices that focus on the emotional and spiritual needs of the elderly will develop more rapidly in the future. Device design targeting the elderly population will be maximized, thus it is necessary to rationalize the emotional needs of the elderly. Matching relationships between device design features and applying them to improved and innovative designs for older devices will also be essential.

1.1.2 Maslow's Hierarchy of Needs Applying for Nursing

Maslow's hierarchy of needs was proposed by Abraham Harold Maslow [113]. The theory can be represented by triangles, which are divided into five phases [61], as shown in Fig. 1.9. The concept of the theory is that human needs can be divided into two levels, low-level and high-level. Low levels of demand refer to physiological needs such as food, water or rest. Conversely, high-level needs mean potential development needs, such as creativity. In humans, each person hides five different stages of demand. The needs in each stage are varied at different times.

Human behaviors can be explained through Maslow's hierarchy of needs. It is also possible to be used for the patients and the elderly.

There are five levels in Maslow's level of needs. From the first level to the fifth level: 1. physiological needs; 2. safety needs; 3. belonging and love needs; 4. self-esteem needs; 5: self-realization. In the first level of needs, it involves the fundamental needs of humans, for instance, food, rest, and life. In the second level of needs, safety needs represent that people require for their own security. Such as, people must guarantee that property is protected in a safe condition; or, they have to prevent getting sick from various diseases. In the third level of needs, it describes that people require the sense of belonging (friendship) and love needs (love). People need good relationships with friends and colleagues. Additionally, people desire to love someone, and people also desire to be loved. These descriptions depicted that people demand belongingness sense in a group, and they desire that the members of a group can concern and love to each other. In the fourth level of needs, people demand to possess a stable position in society, such as in the company. They want to know society's recognition of their personal abilities and achievements. In the fifth level of needs, people desire to realize their cogitations, ambitions and dreams. People would like to fully demonstrate their personal abilities and finally achieve the required things.

Maslow's hierarchy of needs is widely employed in various fields. In this study, the author would like to use this theory to understand the mental state of the patients and the elderly. Thus, the author investigated the Maslow's hierarchy of needs for nursing [114-115]. The five levels of theory indicate the patient's motivation which from injury to recovery during rehabilitation.

Maslow's hierarchy of needs applying for nursing, as shown in Figure 1.10. For the first level of needs, patients would like to reduce nausea, pain and high discomfort [62]. In order to meet the needs of patients, medical staff would prepare the medication to make them alleviate these pains. The patients would thus reach the first level of needs.

In order to elevate the level of needs, from the first level to the second level, medical staff would stably provide the well medication and treatment to make them feel safe because they can reduce nausea, pain, and discomfort. On these two levels of needs, through the well medication and treatment, the patients can be satisfied with the physiological needs and safety needs. However, these levels belong to the basic needs. The next level of needs involves to the psychological needs of patients.

In the third level of needs, friends, lovers, parents, and siblings play vital roles. Patients would like to be more concerned, cared, and shared by them. The people who have high relationships with patients should give mental support to the patients. It can induce better recovery further reach love needs. There is some example in the actual situation: medical staff will remember and celebrate the birthday of patients even though it is long-distance calls. Careful attention through these medical staff, the patients will become delighted and satisfied; further, they will open their minds to the medical staff then achieve the belongingness sense.

In order to reach the fourth level of needs, it is necessary to give respect to the patients. In the actual situation, the patients would desire to share their own experience with medical staff, and through the reaction of the audience, the patients desire to gain achievements and make him feel fulfilled. In this level, the patients are eager to gain self-esteem and be respected. It is able to make the patients re-recognize themselves.

In the fifth level of needs, the patients' t

. During this level, the patients can maintain high motivation for continuously performing the rehabilitation. Thus, if we can promote the patient's enthusiasm for rehabilitation at this level, the patients can achieve the highest effectively assistance in rehabilitation. From Maslow's theory applying for nursing, it is necessary to study not only physical assistance but also mental assistance.

Maslow's needs, emotional design, user experience level and physical design are not absolutely isolated, they cross each other and complement each other to form a complete system. Based on the emotional needs of the improvement, starting from the spiritual level, emotion, and dignity in the first place, to help the elderly and patients achieve a sense of security and confidence. Through the integration of multiple target appeals, designing the function of the device, in line with the cognitive ability, behavioral characteristics and psychological expectations of the elderly and patients in terms of information interface and operational feedback, thus achieving the emotional needs of the people.

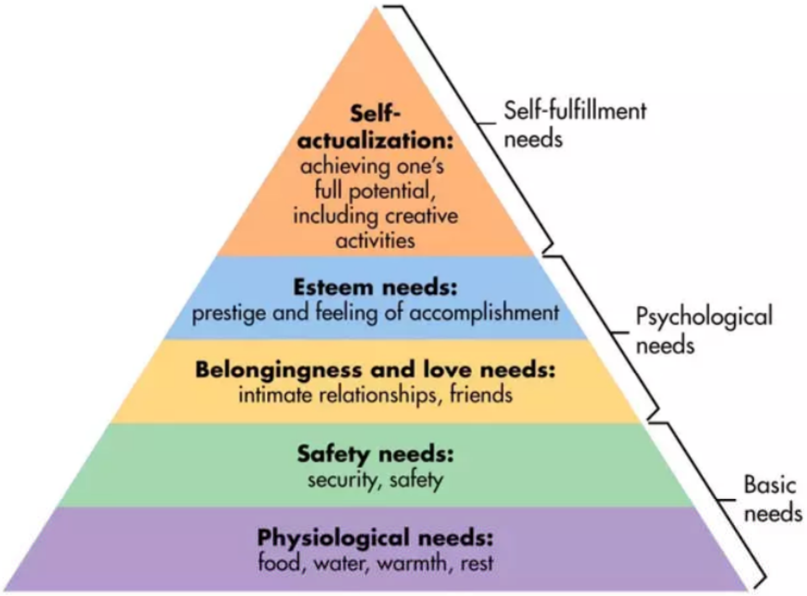


Figure 1.9. Maslow's hierarchy of need [61].

Figure 1.10. Maslow's hierarchy adapted to hospice and palliative care [62].

1.2 Research aim

With aging population worldwide, the issues of the promotion of exercise are gradually concerned to prevent a stroke for the elderly. Proper walking exercise is a good way for the prevention of a stroke in the elderly. However, long-term exercise involves much tired, impatient, and discomfort, which causes the elderly hard to continue it. Effective training is difficult achieved if it does not maintain the elderly's mental intentions. To keep motivation during exercise is thus a vital issue. The current assistive device could provide the powered support to reach the physical requirement rapidly for the user; however, meanwhile, they could not satisfy their mental feelings. Thereby, an assistive device integrates the emotion evaluation that is necessary to be proposed to offer the dual assistance of physical and mental for keeping the motivation during exercise. From Maslow's hierarchy of needs using in nursing, if the body feels much painful and exhausted, it is difficult for anyone to continue the exercise task. On the contrary, if the sense of accomplishment can be repeatedly reached, it is the best situation for keeping motivation while doing exercise. This thesis aims to study on walking assistance considering emotion evaluation, as shown in Fig. 1.11. Furthermore, a strategy for the promotion of positive emotion while using the assistive walking device is also deeply investigated. To achieve the purpose, a hybrid system integrating emotion recognition and a compact walking device is proposed. Finally, the elderly are thus expected to regain self-confidence, live alone, and without other people's help.

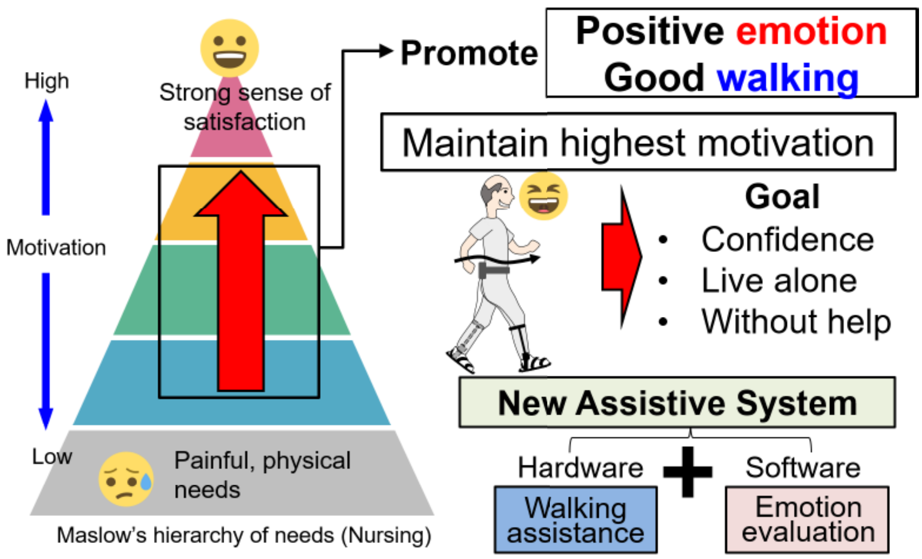


Figure 1.11. Research aims on promotion of positive emotion and good walking for maintaining motivation during exercise.

Chapter 2

Previous Studies

2.1 Physical Assistive Walking Device

Since the 1960s, several researchers and engineers have been developing and studying the lower limb assistive devices (LLADs) [26]. At present, the exoskeleton has its unique advantages in all major fields, and the research on the direction of the exoskeleton of the lower limbs is on the rise. There are two main factors that make exoskeleton research a hot topic. Many LLADs have been developed for supporting individuals whose lower-limb has weakened and whose gait impairment.

Wearable assistive devices have been receiving considerable attention in academic circles. Many researchers and engineers have been proposed various assistive devices for gait impairment and rehabilitation as shown in Fig. 2.1.

Hybrid Assistive Limb (HAL®) [27] had been developed by Cyberdyne. HAL® is a powered exoskeleton to physically augment lower-limb power and restoration of gait for people. This exoskeleton built the sensors to recognize the people's intention of motion, and further assist people to reduce the burden in walking and standing by using three actuators on the hip, knee, and ankle joint. However, HAL® is quite hard to wear; also, it is quite heavy while wearing it. These reasons will become the users' extra burden. Honda walking assist (Stride Management Assist (SMA®)) [28] had been developed by Honda. SMA® was designed aiming at maintaining the impaired walking ability of elderly people or patients. The sensors built in the motor to identify the motion, and then guide the movement of the hip joint. However, the assistive power of this device is weak, which causes not enough assistance effect for the different users. ReWalk™ [29] aims at assisting the people with spinal cord injury to recover their physical function. This device includes the two actuators on the hip and knee joints, which motion is controlled by a wrist pad for supporting sitting, standing, and walking. Curara aims to promote the walking motion of the elderly and patients. Curara includes two motors on the hip and knee joints. By detecting

t

-Foot Orthosis (AAFO) was developed to avoid the foot drop and toe drag issue for people [31]. AAFO used the series elastic actuator to control the ankle movement of dorsiflexion/plantarflexion. Nevertheless, the device is bulky that may encounter an unpredictable accident while walking, such as falling and stumbling. A walking support shoe [32] by moving pneumatic technology is proposed to generate the power to achieve dorsiflexion assistance. The shoes focused on assisted dorsiflexion motion in walking. Nevertheless, the assistive power is weak, which cannot validly assist the dorsiflexion motion in the different weight users. RE-Gait® had been developed to support hemiplegic patients for neuro-rehabilitation [33], and it is able to assist users' ankle dorsiflexion to stretch gastrocnemius, which leads to reflex muscle contraction of knee and hip joint to walk smoothly. RE-Gait® used the strong driving power motor and high stiffness frame, which were suitable for stroke patients who cannot freely control their lower-limbs. Walk-Mate [34] is a walking assistance system on the basis of the co-creation system, which was proposed by Miyake et al. Walk-Mate dedicated to helping the people who have gait disorder by using the rhythm sound further achieves the effect of gait training. However, we believe that only the auditory effect is not sufficient to directly change gait behavior. It is necessary to combine physical assistance while using this device.

The author sorts out the assistive devices of gait impairment and rehabilitation, which indicated in Table 2.1.

In order to make walking easier and enhance walking, a number of LLASs have been designed to augment human walking as shown in Fig. 2.2 and reduce metabolic energy consumption [35-38]. Sano et al [39] developed the non-power walk assistance device for stroke hemiplegia and the elderly. This device used cam with spring to achieve the walking promotion effect. However, the assistance power of the proposed devices is quite weak, it thus cannot give the fully support feeling to users. Additionally, this device is not effective for poor posture users. Collins et al. [40]. proposed a lightweight unpowered exoskeleton that employed the combination of spring and ratchet to provide enough power in the push-off phase. They claimed that an unpowered exoskeleton validly reduces the energy cost of walking. However, this device is triggered by ankle angle while movement; whereby, this device exists the problems: different gait (such as step length, speed...etc.) would not receive the same assistance effects. Galle et al. [41] published an ankle exoskeleton that employed the pneumatic muscle to provide great power in walking. Compared to normal walking, it is able to reduce metabolic costs while using this exoskeleton. However, the pneumatic device is hard to apply in daily life. Mooney et. al. [42] designed an autonomous exoskeleton, which used a DC motor together with a pulley transmission system to generate the high power for walking propulsion. Nevertheless, the weight of this exoskeleton is heavy, which would lead to extra energy cost while walking for a long time. Bionic boot [43] was developed by Seymour. This boot used the elastic material to create the energy while the boot striking on the ground, then, release that energy to accelerate while movement. However, this boot is relatively dangerous and bulky, which is not suitable for the elderly and patients. Louis et al. [44] designed a soft robotic exosuit, which utilized the actuator to drive Bowden cable for assisting plantarflexion and dorsiflexion, which gives the assistance of post-stroke patients. However, the users should wear a 2.63 [kg] actuator on the waist. For the patients and elderly, it is quite heavy. XPED2 [45] is a passive wearable exoskeleton which, was proposed by Dijk et al. XPED2 used the concept of exotendon, which applied the long elastic material span the joints of the lower limb. The exotendon could temporarily provide and transmit the energy among joints. Therefore, users' joints burden can be reduced; further, users can achieve easily walking while using XPED2. However, the whole mechanism is quite bulky and heavy. It is hard to wear it.

From the literature exploration, the author observed the most of devices had the problems of bulky, heavy and weakly power output. Owing to these reason, some existed device proposed an ankle- assist device to reduce the size. However, it still not small enough due to high power motor use. To keep the elderly's healthy by exercise, they do not need high power support. By only informing correct motion and timing, they can gain the promotion of exercise. The means of a very small motor is thus needed to be proposed for an assistive device.

The author sorts out the assistive devices of walking augmentation, which indicated in Table 2.2.

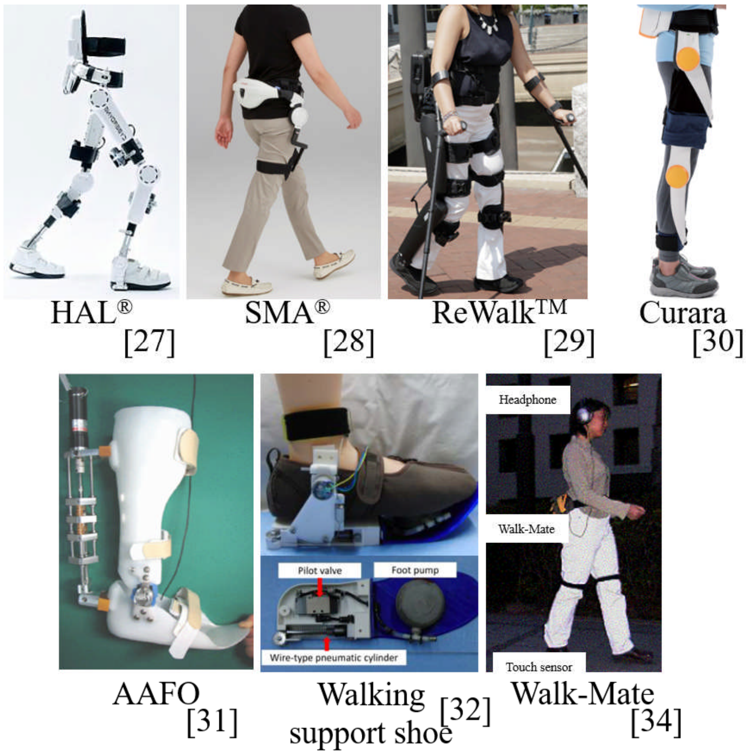


Figure 2.1. Wearable assistive devices of gait impairment and rehabilitation.

Figure 2.2. Wearable assistive devices of walking augmentation.

TABLE 2.1: Comparison of devices of gait impairment and rehabilitation.

	Users	Actuator	Assist position	Characteristic
HAL® [27]	People	DC motor	Hip, knee, ankle	Teach user with the mode of healthy user's mode
SMA® [28]	People	DC motor	Hip	Easy to use, but not very powerful
ReWalk™ [29]	The disabled	DC motor, spring	Hip, knee	Prevent falls through crutch
Curara [30]	Elderly& post-stroke	DC motor	Hip, knee	Mount a special trajectory generation method: Neural oscillator
AAFO [31]	Patients	Series elastic actuator	Ankle	Control the dorsi/-plantarflexion of the ankle joint to prevent foot drop and toe drag
Walking support shoes [32]	Patients	Pneumatic	Ankle	Assist dorsiflexion motion ;Weak power
RE-Gait® [33]	Patients	Servo motor	Ankle	Prevent tripping
Walk-Mate [34]	Elderly	Non	Non	Using rhythm to promote rehabilitation effect

T

Device	Users	Actuator	Assist position	Characteristic
A		(cam with spring)	Hip	Weak power, no use for poor posture of user
Unpowered Exoskeleton [40]	People	Passive (ratchet with spring)	Ankle	Light, high power
Powered ankle-foot exoskeleton [41]	The disabled	Pneumatic muscle	Ankle	Hard to apply in life
Autonomous exoskeleton [42]	Elderly& post-stroke	DC motor	Ankle	High power; Accurate, bulky
Bionic Boot [43]	Patients	Passive (elastic element)	Ankle	Fast motion; hard to wear
A soft robotic exosuit [44]	Patients	linear actuators with Bowden cable	Ankle	Light, accurate assistance; Hard to wear
XPED2 [45]	Patients	Passive (elastic element)	Ankle	Bulky, hard to wear

2.2 Emotion Recognition Technique

Understanding people's minds is a huge difficulty in the world. Therefore, many researchers are committed to studying people's emotions. Emotion is an intrinsic and subjective feeling of people. Therefore, knowing emotions may understand people's mental state. Emotion recognition is the key technology of human-computer interaction. Recent research on emotion recognition has focused on facial expressions, speech, posture, and physiological signals [46], but since the understanding and expression of emotions promotes communication between people, human-machines that focus on user emotional information the interactive method is more appropriate. Physiological signal-based emotion recognition has significantly different characteristics than using speech and image elements. Therefore, the former method has become an important direction in the field of emotional computing [47].

Psychology and physiology provide evidence of a strong correlation between physiological responses and human emotional states. For example, physiological signals are directly controlled by the autonomic nervous system and are not subjectively affected by the subject. Therefore, the recognition results become more realistic and objective [48]. By measuring the electrocardiogram (ECG), the arousal mood can be assessed by the ratio of the sympathetic value to the parasympathetic value [49]. Agrafioti et al. [50] dedicated to analyzing the ECG pattern to determine the awake state of emotional recognition. In addition, facial electromyography (EMG) is a technique for monitoring facial muscle activity. In order to recognize emotions, the activity of muscles and wrinkles is often used to identify valence emotions such as smiles and frowns. Previous studies have studied individual differences in emotional perception based on facial EMG signals [51]. In addition, electroencephalography (EEG) analysis is one of the most effective ways to identify emotions. An emotion recognition method based on EEG features is proposed [53]. Lin et al. [54] proposed a framework for dealing with EEG-based emotion recognition. Learning EEG is effective for understanding people's emotions. Boccanfuso et al [119] employed the temperature of nose as a index to detect emotion, but it is hard to use owing to the very slight value change. Chanel et al [120] only used brainwave information to recognize the human emotion. Their system can only measure two emotions state that is not suitable for the real situation. In general, previous studies used a single physiological signal to judge emotions, while ignoring the fact that different emotional states may trigger multiple physiological signals, and fusion analysis can more accurately identify specific emotional states. Some researches not only utilized one signal to measure the emotion conditions, but also several signals.

Emotional recognition technology is very useful in all areas. Especially in the process of rehabilitation, it is necessary to understand the mental state of the patient, which can enable medical staff to understand their condition and further provide psychological help to the patient.

The existed emotion recognition systems had problems of only a few states prediction and using outer physiological signals (such as voice and facial motion) t

In order to obtain a person's true emotions and prevent the person's own emotion recognition system from producing effects, it is better to apply an internal physiological signal (EEG, ECG, SC) t

(facial expression, EMG). The author sorts out the previous studies shown in Table 2.3, and 2.4.

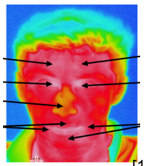
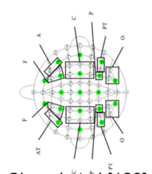
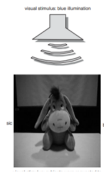
	 Boccanfuso, et al [119]	 Chanel et al [120]	 Kim et al [59]	 Tsiourti et al [119]	 Künecke et al [51]
Physio. signal	Temperature of nose	Brainwave	Heartbeat & electrodermal	Voice& Body	Muscle activities
Stimuli material	Film clips	Pictures	Pic. & Music	Film clips	Video
Accuracy	Pleasure :77.5 %	Arousal: 72.5 %	Arousal: 61. 8%	Pleasure: Arousal: 88 %	Arousal: 75 %
Emotion states	2 states	2 states	4 states	3 states	6 states

TABLE 2.3: The existed emotion recognition technique.

TABLE 2.4: Comparison of emotion recognition system.

Author	Signals	Emotion model	Description and accuracy
Agrafioti, F., Hatzinakos, D., Anderson, A. K., 2012 [50]	ECG	2-D emotional model-4 classes	Affective Dimensional Models Recognition accuracy: 89%
Künecke, J., Hildebrandt, A., Recio, G., Sommer, W. and Wilhelm, O., 2014 [51]	EMG	Discrete emotion mode six emotional states	Independent emotion classification Recognition accuracy: 75%
Mehmood, M. R., Du, R. and Lee, H. J., 2017 [53]	EEG	2-D emotional model-4 classes	LDA, KNN, SVM, naïve-Bayes, random-forest, deep-learning and ensemble methods Recognition accuracy: 76.6%
Lin, Y., Wang, C., Jung, T., Wu, T., Jeng, S., Duann, J. and Chen, J., 2010[54]	EEG	2-D emotional model-4 classes	MLP and SVM, for EEG classification Recognition accuracy: 82.3%
Tripathi, S., Acharya, S., Sharma, R. D., Mittal, S. and Bhattacharya, S., 2017 [55]	EEG	2-D emotional model-4 classes	CNN and DNN classification method Recognition accuracy: 67.8%
Li, L. and Chen, J., 2006 [56]	ECG, SC, SKT, RSP	Discrete emotion model- fear, neutral, joy	Overcome the high dimension classification difficulty Recognition accuracy: 85.3%
Gouizi, K., Reguig, F. B. and Maaoui, C., 2011 [57]	EMG, RV, SKT, SKC, BVP, HR	Discrete emotion mode six emotional states	SVM technique for classifying Recognition accuracy: 85%
Basu, S., 2015 [58]	GSR, HR, RR, ST	2-D emotional model-4 classes	Use Linear and Quadratic Discriminant Analysis Recognition accuracy: 81%
Kim, J. and Andre, E., 2008 [59]	ECG, EMG, SC, RSP	2-D emotional model-4 classes	SBS and the pLDA classifier for arousal and valence Recognition accuracy: 75%
Maaoui, C., Pruski A. and Abdat F., 2008 [60]	BVP, EMG, SC, SKT, RSP	Discrete emotion mode six emotional states	Fisher discriminant and SVM method Recognition accuracy: 92%
Tsiourti, C., Weiss, A., Wac, K., 2019 [119]	Voice, Body, and Context	Mainly 3 emotion recognition	logistic regression Recognition accuracy: 88%

2.3 Consideration of Mental and Physical

To reach the aim of maintaining the motivation and long-term exercise, there is one assistive device which have considered mental and physical aspect of the user. Lokomat [120] is a assitive device which can assist the three joints (hip, keen, and hip.) of the people for rehabilitation, as shown in Fig. 2.3. Meanwhile, Lokomat have proposed to make user longer walking by preparing the task-specific performance (such as video game). However, this device could not understand the emotion of people. It is difficult to define the users' motivation is maintained.

Figure 2.3. The device (Lokomat) used for rehabilitation by assisting three joint of lower limbs [120].

2.4 Research Purpose

The previous studies were explored that include walking assistance and emotion recognition. The existed device proposed an ankle- assist device to reduce the size. However, it still not small enough due to high power motor use. To keep the elderly's healthy by exercise, they do not need high power support. By only informing correct motion and timing, they can gain the promotion of exercise. The means of a very small motor is thus needed to be proposed for an assistive device. Besides, the existed emotion recognition systems had problems of only a few states prediction and using outer physiological signals (such as voice and facial motion) t evaluation and walking assistance for effectively enhancing the effect of assistance during the exercise and rehabilitation. This thesis respectively studied the method of walking assistance, emotion recognition and also explored the emotion-walking relationship. Moreover, to make the users achieve more effectively assistance, using walking strategies to promote and keep the people's emotion was proposed to be applied to this system. After that, the emotion-walking control system was constructed (Fig. 2.4). To complete this system, this dissertation was divided into six chapters. The purpose of each chapter as follows:

In chapter 1, the author introduced the research background and explore the extended problems of the aging population.

In chapter 2, the author studied and explored the existed problems of previous studies, which include walking assistance, emotion recognition, and the method of elevating assistive effects. To resolve these existed issues, walking assistance considering emotion evaluation applies to a compact design device was proposed.

In chapter 3, to extend the target users of the existed walking device, the author proposed a small and lightweight assistive walking device integrating a compact torque limiter (safety factor closes to 1) for assisting both lower limbs to further promote the walking exercise in the elderly and patients. The limit torque and durability tests were conducted to assess the effectiveness of the torque limiter. Additionally, various experiments of walking trials were conducted to evaluate the effectiveness and applicability of this device.

In chapter 4, to understand the people's emotions, a real-time emotion recognition system based on the multiple physiological signals was proposed. Through emotion elicitation experiments, the huge physiological signals corresponding to the questionnaire response built a dataset further constructed a deep neural network as the emotion recognition system. Verification experiments were conducted to show the feasibility of this system in the actual situation.

In chapter 5, to connect the emotion and walking, the emotion-walking relationship was explored by the proposed method. After that, a hybrid assistive system was developed to synchronously fulfill assistance of the physical and mental aspect. To attain more effective assistance effects, the walking strategies were proposed to stimulate and maintain the users' positive emotion. The experiments verified the effectiveness and applicability of this system.

In chapter 6, the author concluded each chapter's conclusion and described the future works.

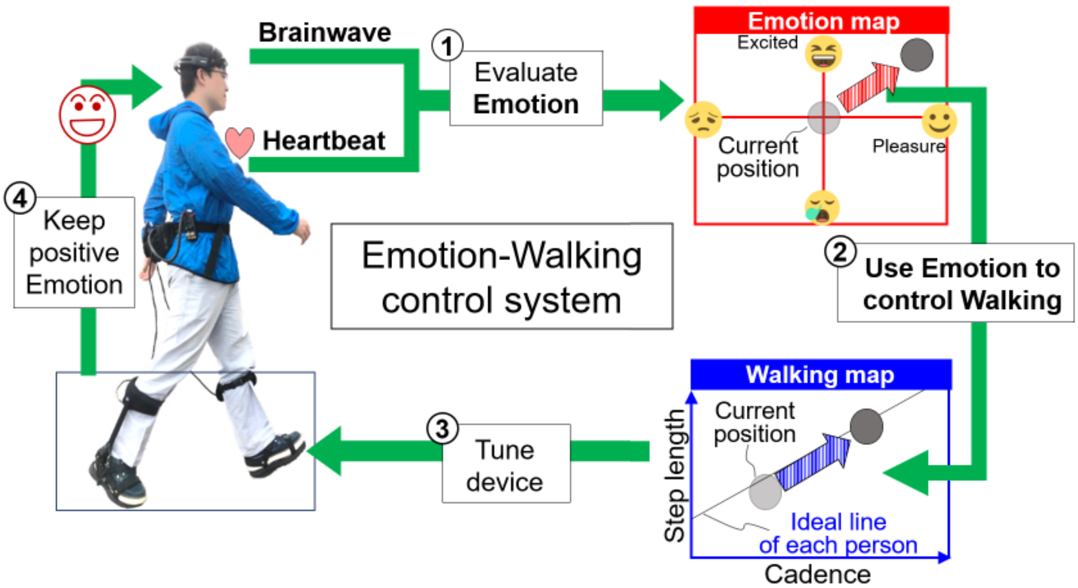


Figure 2.4. Hybrid approach integrating physical and mental assistance.

2.5 Dissertation Framework

From the extended problems of the aging population, the observation showed that there are mainly divided into two issues, one is physical condition (muscle atrophy, cardiovascular disease, and metabolic disease); another is mental state (emotional management, self-confidence, and frustration). These issues make the elderly lead to stroke; after stroke, the same issues of physical and mental happened in the patient. To solve the physical issues, proper walking exercise together with an assistive device is used to regain body conditions. Whereby, it is necessary to design a new assistive device for the promotion of exercise. In order to resolve the mental issues, recognition of emotion is a good method for understanding the people's mind. Whereby, it needs to develop a recognition system that can real-time identify the emotion of people. Moreover, physical and mental issues easily happen simultaneously; hence, to resolve these problems, the study of walking assistance considering emotion evaluation was proposed. The framework of this dissertation(Fig. 2.5) is constructed in the following chapters:in chapter 1, the research background is explored to understand the extended issues of the aging population. In chapter 2, by searching previous studies, the author aims at resolve the currently problems in rehabilitation and exercise;thus, walking assistance considering emotion evaluation applies to a compact design device was proposed. In chapter 3, the author aims to develop a new compact assistive walking device for assisting for biped assistance. In chapter 4, the author aims to develop a real-time emotion recognition system to predict the real emotion of people. In chapter 5, by integrating the chapter 3 and 4, the author aims to develop a hybrid assistive system which can make the users attain more effective assistance effects. Finally, the author concludes each chapter and described the future works.

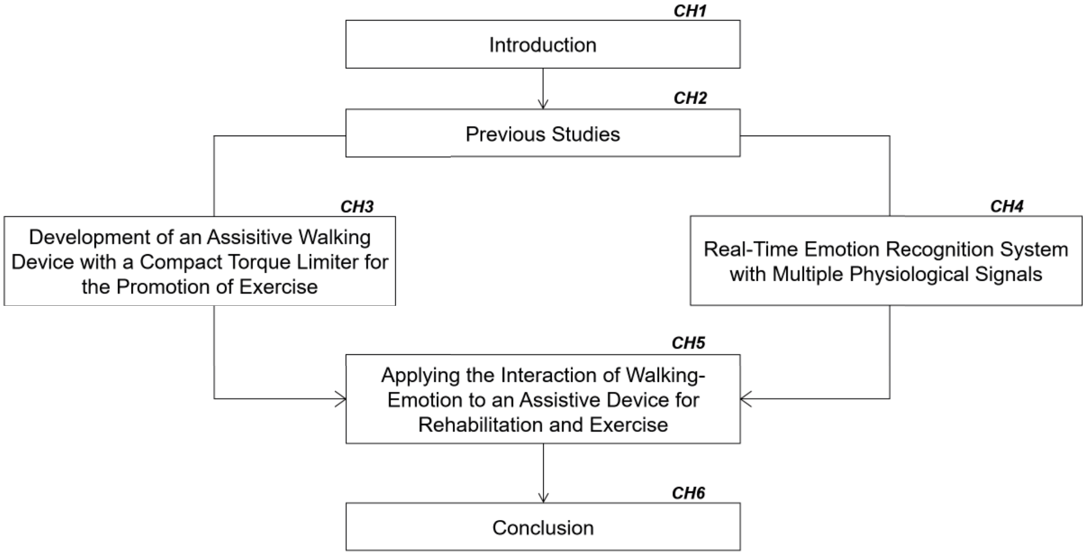


Figure 2.5. Framework of this thesis.

Chapter 3

Development of an Assistive Walking Device with a Compact Torque Limiter for the Promotion of Exercise *

3.1 Abstract

Aging causes the reduction of physical activity, which may lead to the elderly being bedridden easily then leading to stroke. Proper exercise is considered as an idea for the elderly to avoid suffering from a stroke. In this chapter, a compact assistive walking device was proposed for the elderly to promote the walking exercise and gait training. Considering the practical usage of the device, the user usually encounters unexpected walking motion which induces equipped motor easily breakage. To improve the service life of the device, an overload protection mechanism using a torque limiter is developed, which can eliminate the overload torque delivered in the reverse direction to effectively prevent the device from breaking and ensure the safety of the user. We made the material from rubber and configured it between a pair of circular plates. The surface tractive force delivered the required torque. When the surface load exceeded the maximum friction force, the circular plates slipped and protected the device. We implement a torque limiter and prove its durability by performing experiments using two circular plate designs, one with grooves type and another without grooves type. We also use various materials to assess the applicability of this device. Additionally, this study evaluates the effectiveness of this device by measuring the gait kinematics of the subjects. Consideration of walking condition in daily life, the experiments were designed in comparison to wearing and without wearing the device. Through the examination of gait kinematics with statistical evaluation, the findings show that

*This chapter's contents relate to the published journal paper: Zhuang, J.R. et. al, "Development of a Torque Limiter for the Gear of an Assistive Walking Device," Journal of Advanced Mechanical Design, Systems, and Manufacturing, Vol. 11, Issue 6, (2017), Paper No.17-00376 (12 pages) Indicated in research achievement of journal [2]; reference[130] t -off timing, and step length change. F - rect the users' gait to further achieve better gait training and promote the walking exercise for improvement of the quality of life.

3.2 Introduction

The requirement of wearable assistive devices has been increasing due to the growth of aging population worldwide and stroke survivors in recent years. With advanced progress in robotic technologies, several researchers have developed the exoskeletons and orthoses as the assistive device to enhance human economy, strength, and endurance [63]. Age is one of the most significant risk factors for stroke [64], which is still a common cause of death and disability in the elderly [65]. Aging causes muscle strength degradation, cardiovascular and metabolic disease incidence increasing, which influences on the reduction of physical activity. The elderly people are thus being bedridden easily then leading to stroke. The issue of prevention of stroke in the elderly is necessary to study. In spite of some therapeutic medicines being able to suppress the risk of stroke diseases, physical therapy is not negligible. Proper exercise is considered as a suggestion for stroke prevention in the elderly. If the elderly appropriate use an assistive device to do exercise, they can receive the gait training and simultaneously stimulate the neural circuits of the brain, then avoiding getting stroke. Therefore, promotion of exercise is an important topic for the elderly. Many lower-limb assistive devices have been developed for supporting individuals whose lower-limb has weakened and whose gait impairment. Hybrid Assistive Limb (HAL®) [27] had been developed to physically augment lower-limb power for healthy people. Stride Management Assist (SMA®) [28] had been designed to regain impaired walking ability of the elderly or patients. ReWalk™ [29] focused on assisting individuals with spinal cord injury to regain their activities of daily living. Furthermore, Sawicki et al. (2009) [66] proposed the powered ankle exoskeletons to examine the metabolic cost during walking; Collins et al. (2015) [40] also aimed to test the walking energy cost via using the unpowered ankle exoskeleton.

Recent studies [67, 68] developed the robots that utilized the torque limiters to become compliant from stiffness after withstanding force over the threshold. Torque limiters were widely employed to prevent damage when mechanical system occurred in overload situations. K. Atallah et al. [69] described an integrated magnetic torque limiter which was assembled in the permanent magnet brushless motor, and this design could protect mechanical systems from overloads. In

T

Device	Model type	Dimension (D×L) and Weight (W)	Torque [N-m]
Sankyo [106]	TC series-4TC	64×28 [mm]and 0.25[kg]	1.5-4.5
Mayr® [107]	ROBA®-slip hub	45×33 [mm]and 0.3[kg]	2-30
Rexnord [108]	200 Series-Model 203	60×91 [mm]and 1[kg]	1-44
Cross+Morse [109]	Models M30-M30-2	30×31 [mm]and 0.1 [kg]	3-10
Ringspann [110]	RT 30.1	30×31 [mm]–[kg]	0.5-5
Davall [111]	DSF 00.25	25×26 [mm]and 0.06[kg]	1-20
This study	with and without groove	21.15×29.25[mm]and 0.013[kg]	1-4.5

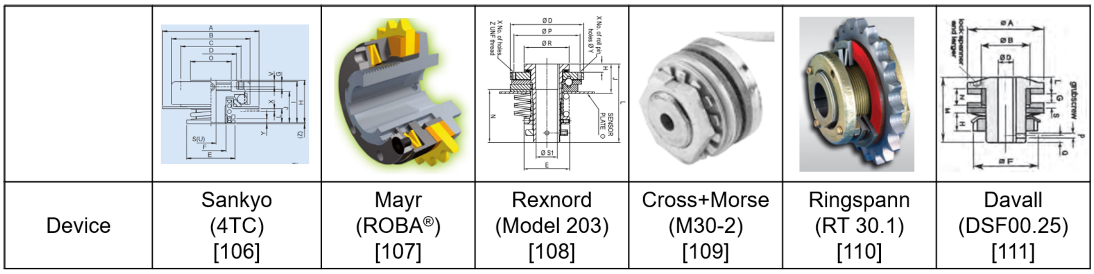


Figure 3.1. Commercial torque limiter appearance.

addition, the overload protection mechanism also has been applied in humanoid robot research. W. Fukui et al. [70] had developed five-fingered robot hand including torque limiter mechanism to protect the driving system when it sustained the large external force. To diminish the damage to a humanoid robot during falling, X. Guo et al. [71] designed the torque limiter on the robotic joint. For confirming the safe use of a manipulator, W. Lee et al. [72] applied torque threshold on spring-clutch mechanism as a safe torque limiter which was enabling to reinitialize its position. Furthermore, we also checked the dimension and weight of commercial torque limiters compared with this study's torque limiter (21.15×29.25[mm] and 0.013[kg]) as illustrated in Table 3.1 and Fig. 3.1. By checking the commercial torque limiter [106-111], the large dimension and weight features would cause the burden of the user. Besides, the complicated design is difficult to assemble to the small motor.

The literature exploration indicated the main features of the commercial torque limiter, there are, 1. delivered torque 2.slipped torque. The key influence of these features is friction force, which needs to achieve exactly value to further generate required torque. Also, it should adequately release the torque when the device encounters overload. This study devotes developing the torque limiter which can obtain the required torque for driven users' foot and released the load when users encounter unexpected movements.

3.3 Purpose

The existed devices so far have shown the problems of heavy, bulky, and weak power. Some devices have been proposed to resolve these issues, however, it still not small enough due to high power motor use. To keep the elderly's healthy by exercise, they do not need high power support. By only informing correct motion and timing, they can gain the promotion of exercise. The means of a very small motor is thus needed to be proposed for an assistive device. Meanwhile, consideration of service life in a very compact device should be attentionally studied to prevent breakage from the unexpected load. Therefore, this chapter aims at developing an assistive walking device with a compact torque limiter for teaching correct timing and motion for the elderly to promote exercise.

3.4 Development of an Assistive Walking Device

From 2016, we had developed the RE-Gait® for stroke patients for neuro-rehabilitation in the medical institution, such as hospital and retirement home. After that, according to the different purposes, we have been trying on designing a new assistive walking device, which aims at giving the elderly to promote exercise. Elderly are at high risk of stroke because aging leads to muscle atrophy, cardiovascular and metabolic disease incidence growing. These problems induce the reduction of physical activity in daily life; with increasing time, the elderly thus suffer from the stroke. To prevention of stroke in the elderly, the promotion of exercise is the practical way in physical therapy. Thereby, a new compact assistive walking device has been developed, as shown in Fig. 3.2.The primary purpose of this device is guiding users to perform the correct timing of dorsiflexion and plantarflexion; whereby, they can be improved the gait further promoting exercise. In the hardware, compared to the RE-Gait® (as shown in Fig. 3.6), a single frame design provides a flexible characteristic for the user to adapt in different terrains while walking; besides, it also reduced the constrained feeling while walking using the assistive device. Moreover, for the convenience of users, they do not need to take off the shoes; thus, they can equip this device while wearing shoes. The pressure sensors (FSR406) [117][137] were installed on the sole of the device for confirming the walking phase of the user; in addition, these sensors are also used as the trigger to actuate the servo motors to work. Two pressure sensors are respectively installed on the position of heel and forefoot as shown in Fig. 3.4 and 3.5. From the pressure sensor value change, the users walking phase can be confirmed. Additionally, the compact servo motor (KONDO-B3M-SC-1170-A) was used in the assistive walking device. This servo motor possessed features of small (51 × 32 × 39.5 [mm]), lightweight (105[g]). This servo motor had a high precision 12-bit non-magnetic encoder (minimum resolution: 0.088°), a gear ratio of 382.88:1, a maximum operating angle of ±320° and maximum continuous torque (rated torque) of τ_{rated} = 4 [N·m][73]. Three control methods could be used in this servo motor: position con- t . This device is smaller, lighter and cheaper (weight: 0.6 [kg/one leg]; price: under $1000) t .

Figure 3.2. A new compact assistive walking device for promotion of exercise.

Figure 3.7 shows the major assistance idea of this device by using a stretch reflex mechanism of human for users walking smoothly. At the end of stance phase, the device assists the plantarflexion motion (blue arrow) to aid the forward motion. After that, at the initial swing phase, the device assists the dorsiflexion motion (blue arrow), which induces stretch gastrocnemius (GAS) muscle (yellow arrow) further leading to reflex bi-articular muscle contraction (GAS and Rectus Femoris (RF) m); finally, the knee and hip joint are flexion inducing foot raise. By activating the human stretch reflex, users can step forward smoothly in walking.

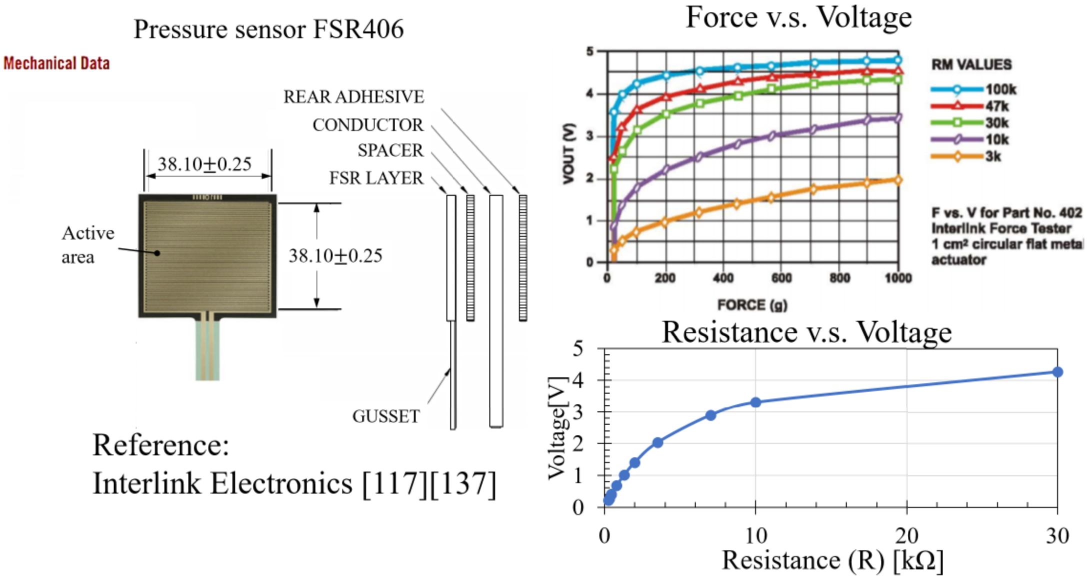


Figure 3.3. Structure of pressure sensor FSR406 and its function [117][137]. Through different load pressure, the voltage can be increased. It thus can use to confirm the walking phase by checking the sensor is activated or not.

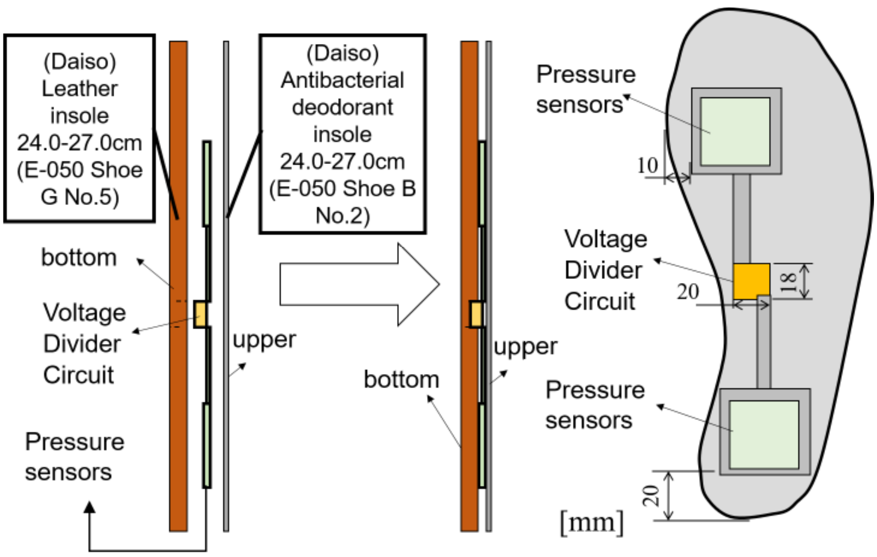


Figure 3.4. Walking phase measurement device using pressure sensor installed on forefoot and rearfoot of shoepad [117].

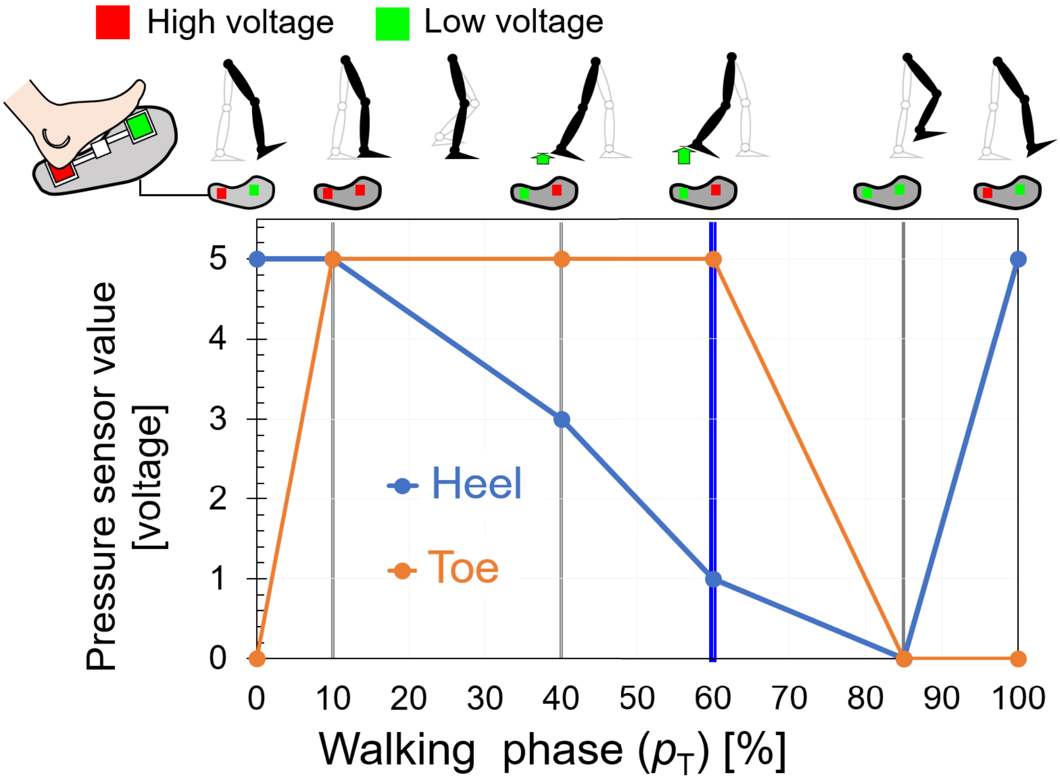
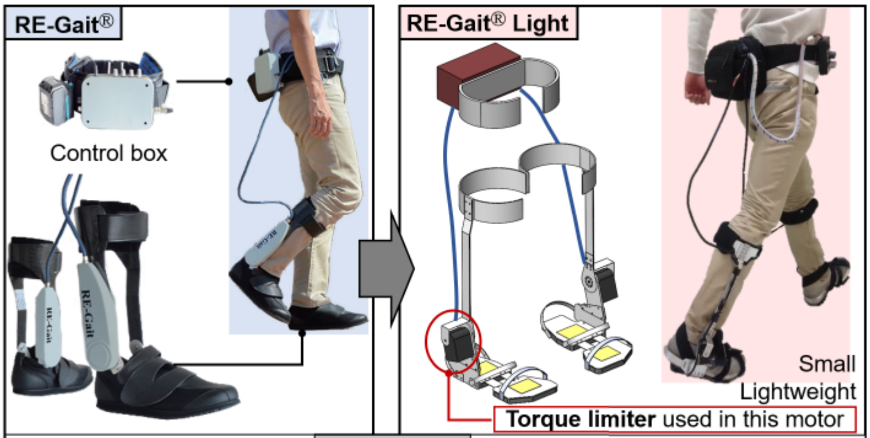


Figure 3.5. Use pressure sensor to confirm walking phase and trigger. By checking the pressure sensor value changing of heel and forefoot, this measurement device can understand the walking phase of the user.

The control system of this assistive device is showed in Fig. 3.8 and Fig.3.9. The device employed the Arduino® as a central control unit to process analog signals from pressure sensors further confirming the walking phase of the users then controlling servo motors. To achieve different assistance in daily life, we programmed the walk mode in the control system [33]. The actuation procedure of this device is showed in Fig. 3.11. θ_T and W_T are target ankle angle and target walking cycle, respectively. $\dot{\theta}_T$ and $\dot{\theta}_M$ are target angular velocity, motor's input angular velocity. Walk mode (angular velocity control) was designed for gait training of the users; in this mode, we set up the target ankle angle ($\theta_{T_{0\%}} \sim \theta_{T_{100\%}}$) t

($p_{T_{0\%}} \sim p_{T_{100\%}}$) into system; whereby, the angular velocity ($\dot{\theta}_T$ [deg/sec]) could be calculated via angle variation ($\theta_{T_{next}} - \theta_{T_{current}}$) divided by walking phases variation ($p_{T_{next}} - p_{T_{current}}$)$\times$ W_T as illustrated in Eq. (3.1). The block diagram is shown in Fig. 3.12.

Walk mode could thus assist the dorsiflexion and plantarflexion at correct timing further



for Patient	User	for Elderly
One leg : 1 [kg]	Weight	One leg : 0.6 [kg]
Rehabilitation	Purpose	Promote exercise
For medical institution	Application	For personal use
Rigid design (two frame)	Hardware	Flexible design (one frame)
Cannot wear shoes on device	Convenient	Can wear shoes on device

Figure 3.6. Comparison of RE-Gait® with a new compact assistive walking device.

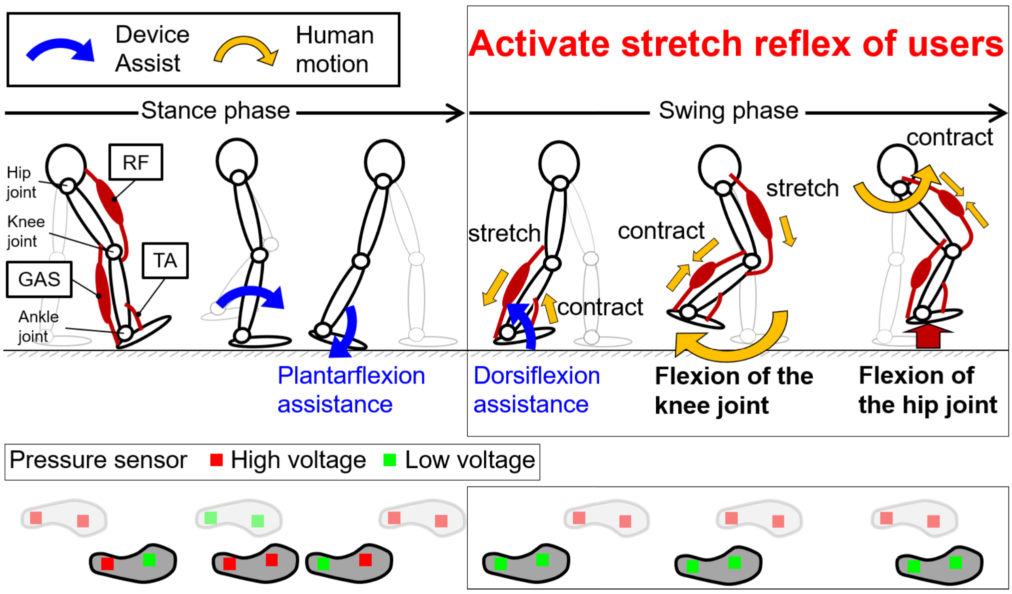


Figure 3.7. The major assistance idea of this device by using a stretch reflex mechanism. Device triggers the dorsiflexion (blue arrow), and then GAS muscle is contracted by stretch reflex, knee joint is thus flexion; then, due to flexion of knee (yellow arrow), RF muscle is contracted by stretch reflex, and thus hip joint is flexion (yellow arrow). Finally, the foot can be raised.

improving and training the users' gait. In this study, we focused on using the walking mode for the users. Predefined target angle of walking mode compared with average data of the able-bodied person shown in Fig. 3.10. To adapt to different users, we programmed the fine-t

(t

) and angle amplitude to match various gaits. This device was developed for personal usage in daily life; thus, to make it convenient for the users, we designed a mobile application in the smartphone (Android 9.0 operating system) to realize the wireless remote control. Thus, users could freely adjust the different assistance effect in walking by using a smartphone. Figure 3.10 also indicated that how to tune and use this device. Through remoter, the user can easily tune their target angle amplitude [deg] and target walking cycle [sec]. Usually, the walking phase [%] is fixed, which is not be tuned by the users themselves. If necessary, it can be tuned the different phase by modifying the program code.

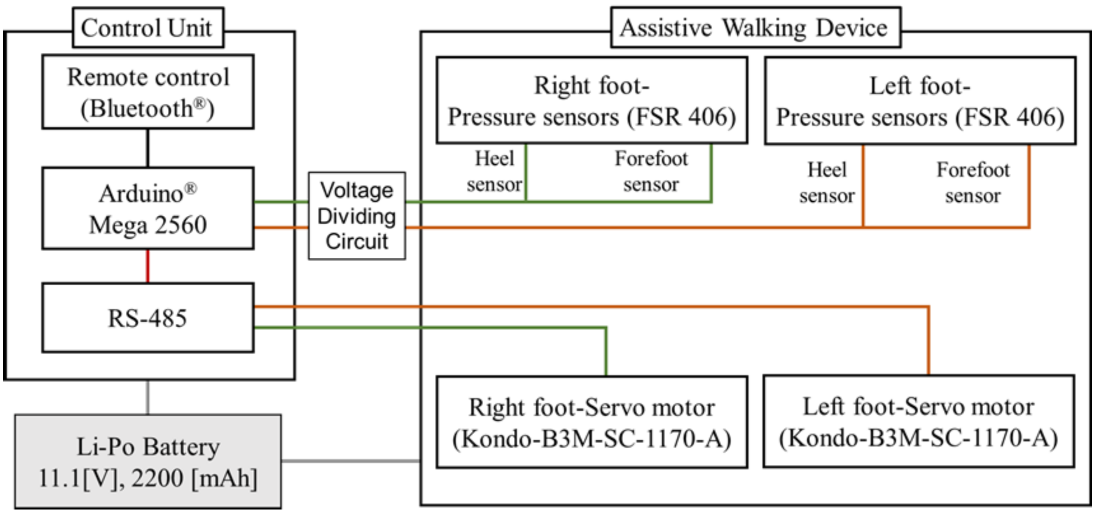


Figure 3.8. The configuration of an assistive walking device.

$$\dot{\theta}_T = \frac{\theta_{T_{next}} - \theta_{T_{current}}}{(p_{T_{next}} - p_{T_{current}}) \times W_T} \times 100\% \tag{3.1}$$

where, $\dot{\theta}_T$[deg/sec] is target angular velocity during one walking phase ($(p_{T_{next}} - p_{T_{current}}) \times W_T$). θ_T [deg], and p_T[%] are corresponding target ankle angle and target walking phase, respectively. W_T [sec] is target walking cycle.

$(p_{T_{next}} - p_{T_{current}}) \times W_T$ is used to give the time of each walking phase. For example, in walking phase 10% ($p_{T_{10\%}}$), the corresponding walking cycle time is $p_{T_{10\%}} \times W_T$ [sec]. If W_T= 1.08 [sec], Thus, 10% $\times$ 1.08 = 0.108 [sec] in walking phase $p_{T_{10\%}}$. In this study, the initial setting of target ankle angle, walking phase, and walking cycle as shown in Table 3.2:

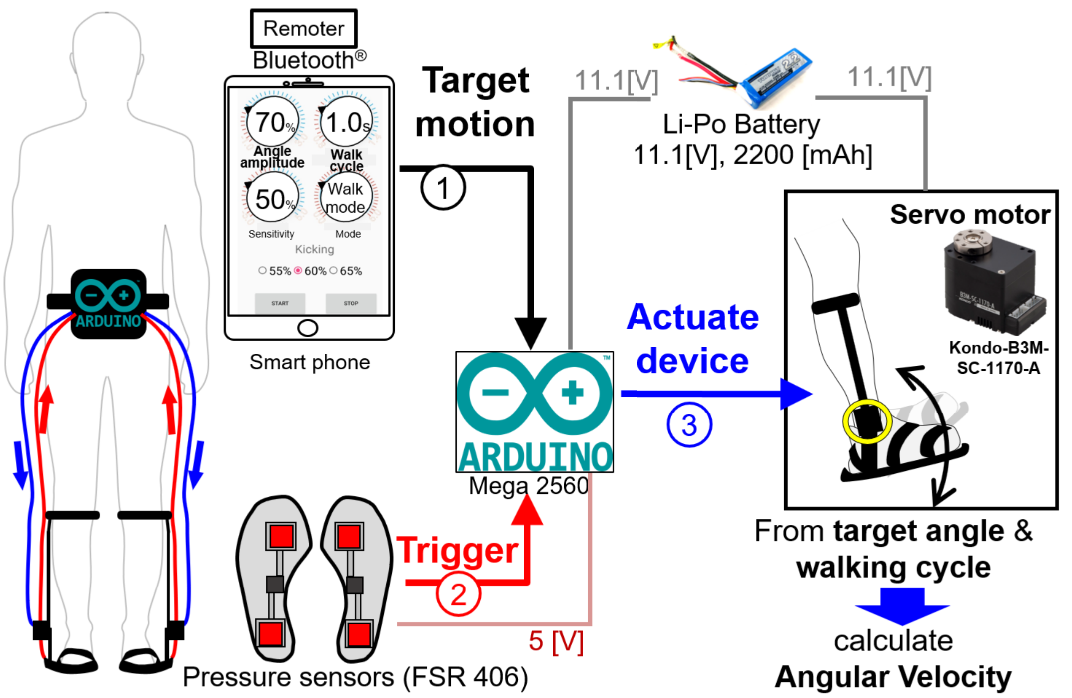


Figure 3.9. The control system of the assistive walking device.

The corresponding walking phase and target ankle angle is plotted on the 2D map as shown in Fig. 3.10: ($p_{T_{0\%}}$, $\theta_{T_{0\%}}$) = (0,0[deg]); ($p_{T_{10\%}}$, $\theta_{T_{10\%}}$) = (10%, -5[deg]); ($p_{T_{40\%}}$, $\theta_{T_{40\%}}$) = (40%, 10[deg]); ($p_{T_{60\%}}$, $\theta_{T_{60\%}}$) = (60%, -20[deg]);($p_{T_{85\%}}$, $\theta_{T_{85\%}}$) = (85%, 20[deg]); ($p_{T_{100\%}}$, $\theta_{T_{100\%}}$) = (100%, 0[deg]).

TABLE 3.2: The corresponding walking phase and target ankle angle.

Initial walking cycle [sec]	walking phase [%]	target ankle angle [deg]
W_T=1.08	$p_{T_{0\%}}$ = 0	$\theta_{T_{0\%}}$=0
	$p_{T_{10\%}}$ = 10	$\theta_{T_{10\%}}$=-5
	$p_{T_{40\%}}$ = 40	$\theta_{T_{40\%}}$=10
	$p_{T_{60\%}}$ = 60	$\theta_{T_{60\%}}$=-20
	$p_{T_{85\%}}$ = 85	$\theta_{T_{85\%}}$=20
	$p_{T_{100\%}}$ = 100	$\theta_{T_{100\%}}$=0

The example of calculation of target angular velocity as shown in Fig. 3.13.

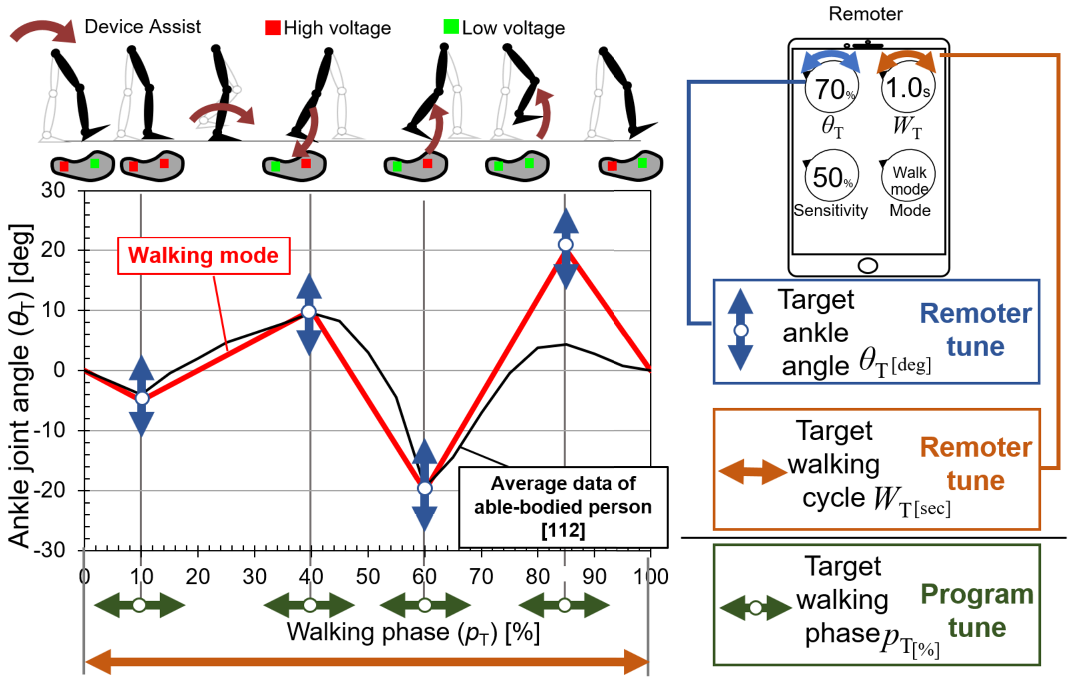


Figure 3.10. Predefined target angle of walking mode compared with average data of the able-bodied person[112].The user can easily tune the target ankle angle amplitude and walking cycle accroding to their own condition. Walking phase is usually not changed. If necessary, it can be tuned by modifying the program code.

3.4.1 Development of a Torque Limiter for the Gear of an Assistive Walking Device

During the walking trial, the wearers of the device frequently encounter unexpected movements that lead to motor failure in the device. To make the device efficient, we need additional research on the service lives of the mechanical elements used in the device. This section described the development of an overload protection mechanism using a torque limiter.

To achieve the compact design, currently, the safety factor would be designed to close to 1. However, the device easily encounters unexpected overloads that lead to a gear broken in the motor as shown in Fig. 3.14. For the prevention of breakage, a compact torque limiter was designed in a gear of motor, which maintains the same size and weight as the original gear. We developed a torque limiter and incorporated it in the final gear to effectively prevent gear breakage in assistive walking devices. Furthermore, the servo motor could use two control methods: position control and angular velocity control. During the development of the assistive walking device, we found that the final gear of the servo motor broke frequently when the subjects tried

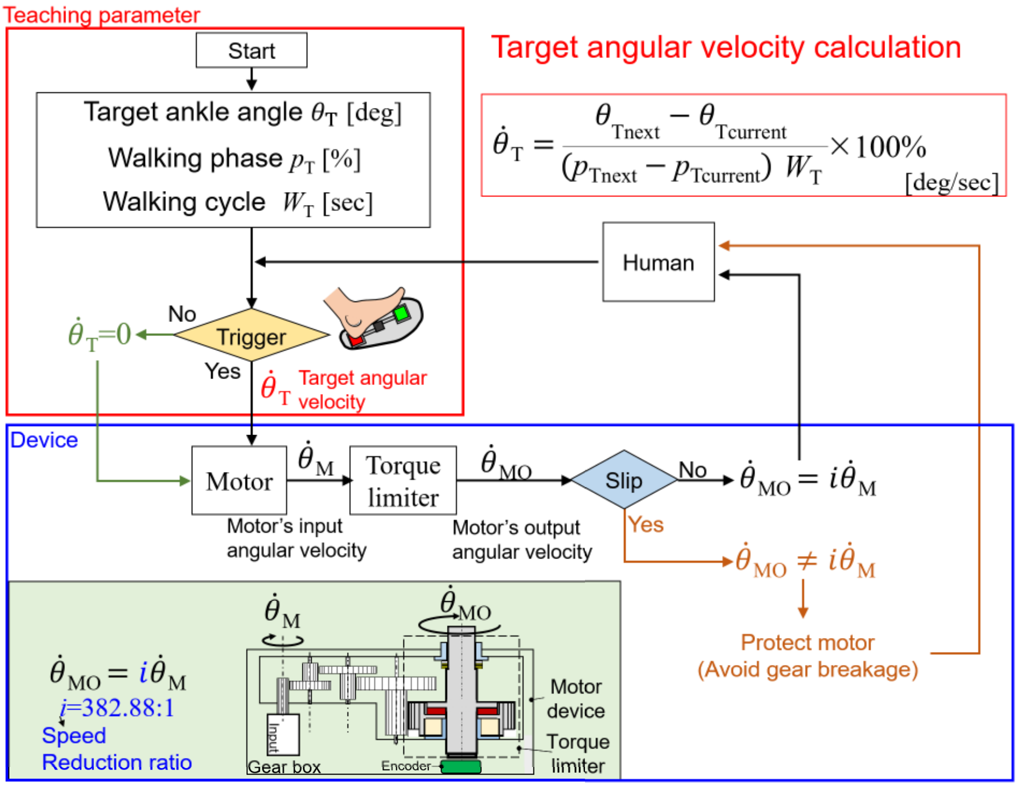


Figure 3.11. Actuation procedure of the assistive device
(1)Give the target ankle angle(θ_T), walking phase(p), and target walking cycle(W_T)
(2)The trigger of the actuation device is defined by 1.walking phase and 2.pressure sensor activation
(3)Target angular velocity ($\dot{\theta}_T$) is calculated via Eq. 3.1. If trigger is satisfied, target angular velocity ($\dot{\theta}_T$) inputs to the motor; if trigger is not satisfied,target angular velocity ($\dot{\theta}_T$) = 0.
(4)When target angular velocity ($\dot{\theta}_T$) inputs to motor, motor generates the motor's input angular velocity ($\dot{\theta}_M$). Then, according to gear transmission (speed reduction ration i=382.88:1), the motor outputs angular velocity ($\dot{\theta}_{MO}$) to actuate the device.
(5)By torque limiter effect, when it slips (encounters overload), it can protect motor from breakage but $\dot{\theta}_M \neq \dot{\theta}_M$. When it do not slip, it can transmit the target motion to the human ($\dot{\theta}_M = i\dot{\theta}_M$).
(6)The device will be actuated again when it the trigger is activated.

it out. As in a real-life situation, the user regularly encountered unforeseen movements, which caused an unexpected input of an inverse torque in the gear box of the servo motor. This broke the gear teeth(Fig. 3.14). We developed a torque limiter to prevent damaging the gear box and maintain the user's safety [130][131][132]. To use the wearable assistive device, it had to be placed directly on the human body. Therefore, we developed the torque limiter because safety

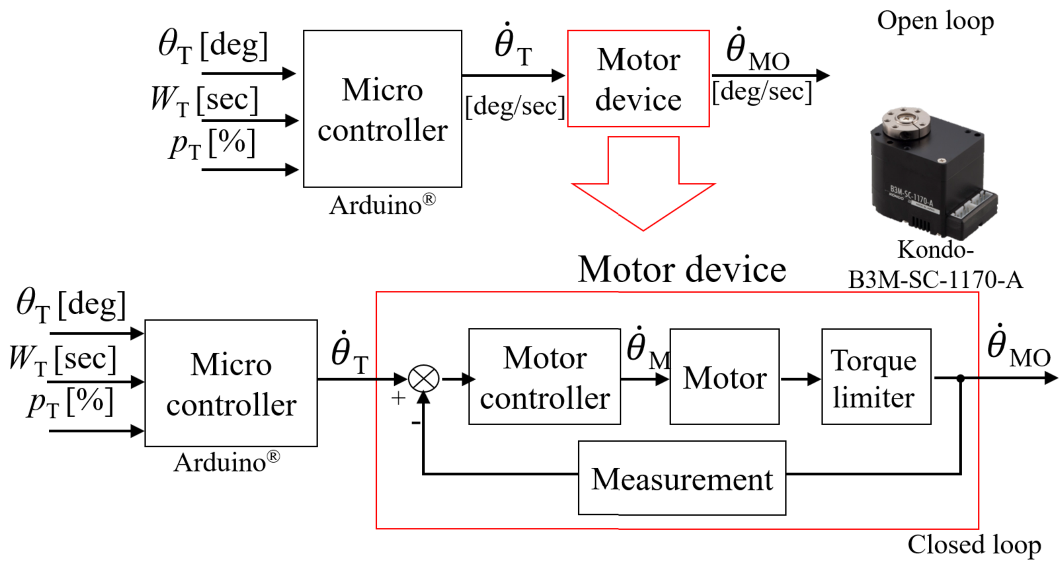


Figure 3.12. Block diagram of an assistive walking device.

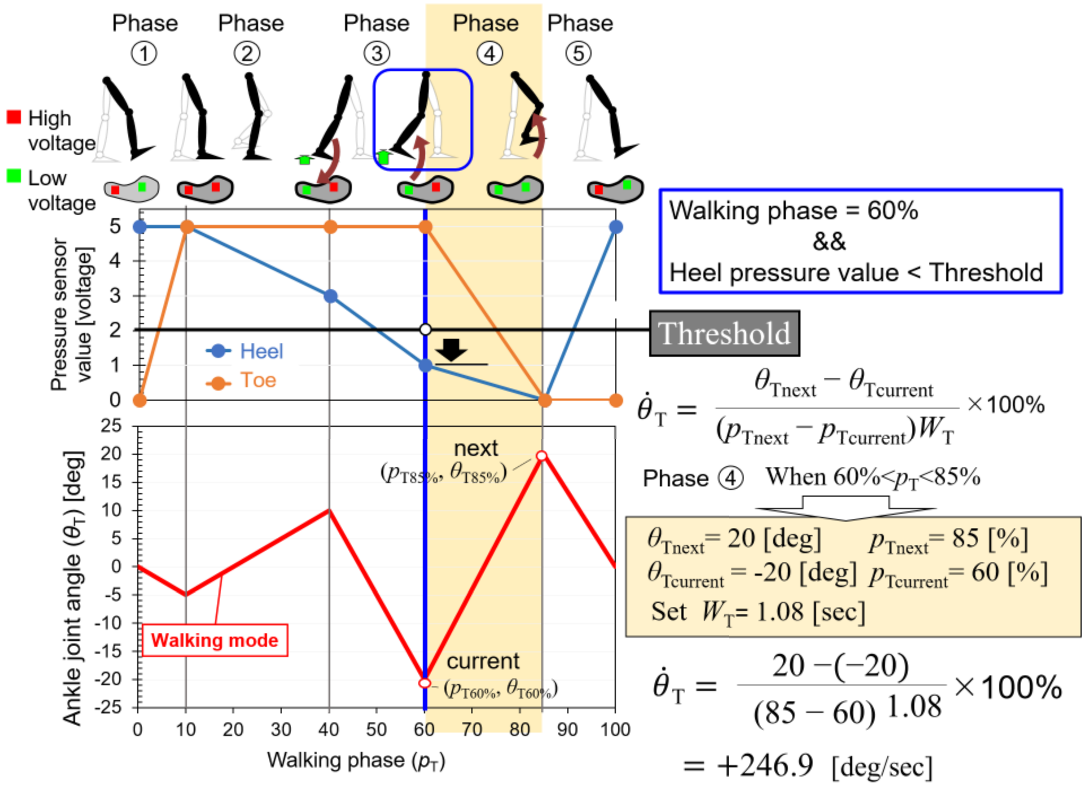


Figure 3.13. Example of calculation of target angular velocity.

issues were a major concern. We used the sandwich mechanism for the torque limiter, which consisted mainly of three parts: 1) the final gear, 2) the output shaft, and 3) t -
cular plate. Figure 3.15 shows the schematic of the torque limiter mechanism. The configuration of the torque limiter is such that the hollow rubber circular plate is arranged between the final gear and the output shaft. The torque limiter mechanism was assembled into the servo motor to work as an overload protection system for the assistive walking device. When using the torque limiter, the output shaft would be subject to an axial thrust that would generate a friction force on the circular rubber plate; this will then drive the rotation torque. This study aimed to develop a lightweight and small-dimensional assistive walking device; therefore, we selected a small motor at the start of the development. However, the gear of the servo motor broke frequently during the practical trials; therefore, we modified the gear of the servo motor. In our design, this torque limiter had the same size and weight as the unmodified gear. Using this design, the servo motor could maintain the volume and weight consistently with the original motor. By using this torque limiter design, we could eliminate the inverse delivered torque and prevent the apparatus from breaking down because of overload; it also simultaneously ensured the safety of the user. Also, it only needs to replace the sandwich material that can be reused. The proposed design could give the readers conveniently complete a torque limiter to achieve the effect of overload protection. Hence, we did not need to use an additional commercial torque limiter for this assistive walking device.

As shown in Fig. 3.16, we used a preliminary design of the circular plate of ϕ14 [mm] to perform the torque limit experiments in the beginning [74]. In this study, we subsequently enlarged the circular plate diameter to ϕ18 [m

) limiting the torque, 2) limiting the torque by increasing the thickness of shim rings, and 3) S-N experiments These experiments provided evidence of the maximum load torque and the durability of the rubber materials used in the different gears.

Figure 3.14. Gear teeth fractured by being subjected to unexpected loads by the user during walking.

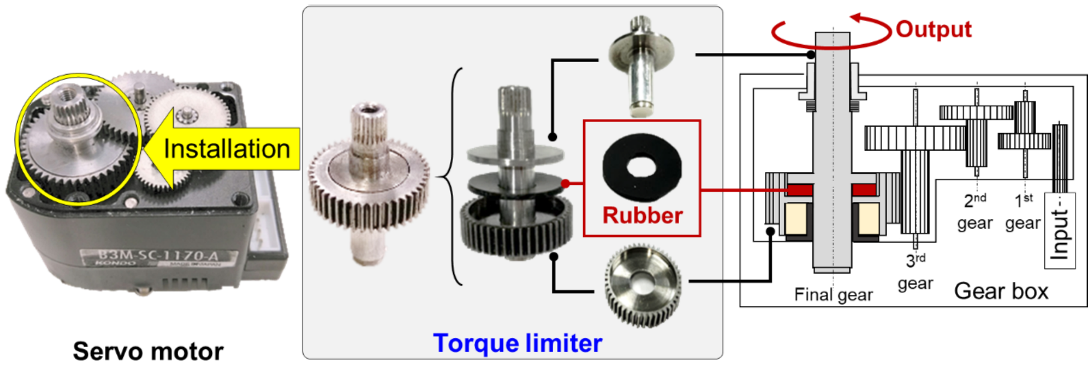


Figure 3.15. Schematic of the torque limiter mechanism consisting of the output shaft, final gear, and sandwich material. The servo motor includes the input shaft, first gear, second gear, third gear, and torque limit mechanism.

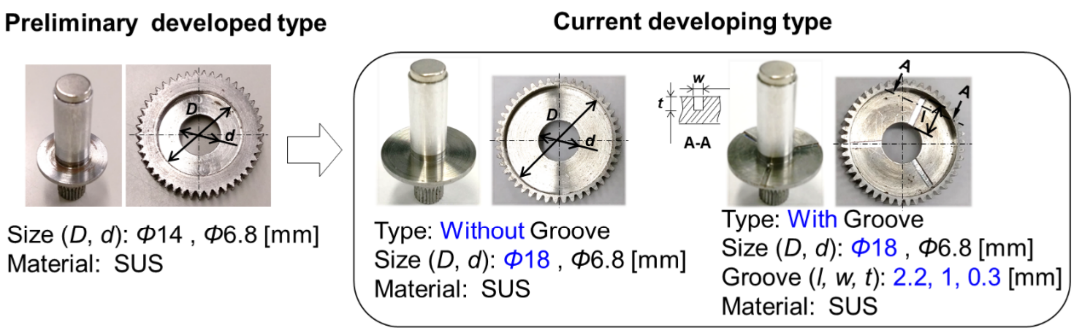


Figure 3.16. Development of the torque limiter mechanism. Previous models used a diameter of $\phi 14$ [mm] to assess the torque performance. In the current model, we increased the diameter and added two types of final gear designs, with and without grooves.

3.4.2 Delivered Frictional Torque

In this study, we developed a torque limiter for a walking assistance device using the frictional torque delivered by the circular plate; this torque was generated because of the friction between the contacting surfaces. The delivered frictional torque plays a primary role in walking assistance devices. In t

. This torque calculation is shown in Fig. 3.17. Thus, the normal force (N) can be calculated as follows [75]:

$$N = P_a \times \frac{\pi}{4}(D^2 - d^2) \tag{3.2}$$

where the N, P_a, D, and d are the normal force, the normal pressure, the external diameter, and the internal diameter, respectively. Then, the delivered frictional torque generated by the without grooves type ($\tau_{w/o}$) would include the torque generated by the normal pressure and the pressure of the lateral side; therefore, $\tau_{w/o}$ can be expressed as follows:

$$\tau_{w/o} = \mu \times P_a \int_{d/2}^{D/2} 2\pi r \times r dr + \mu \times P_s \times A_{side} \times \frac{D}{2} = \frac{\mu N}{3} \times \frac{D^3 - d^3}{D^2 - d^2} + \frac{2\mu N D^2 t}{D^2 - d^2} \tag{3.3}$$

where μ, r, P_s, A_{side}, and t are the friction coefficient, an element of the radius, the pressure of the lateral side, the area of the lateral side, and the thickness of the material, respectively. The delivered torque given in Eq.(3.3) is for a single pair of mating surfaces. Furthermore, the delivered frictional torque of the with grooves type (τ_w) can be expressed as follows:

$$\tau_w = \tau_{w/o} + n \times F_s \times r_m = \frac{\mu N}{3} \times \frac{D^3 - d^3}{D^2 - d^2} + \frac{2\mu N D^2 t}{D^2 - d^2} + n \times \frac{\mu N}{A_c} \times A_g \times r_m \tag{3.4}$$

where n, F_S, A_c, A_g, and r_m are the number of grooves, the local shear force of the groove, the circular contact surface area, the projected area of the groove, and the equivalent radius. In Eq.(3.4), the term $n \times F_S \times r_m$ refers to the additional torque caused by the local shear force from the squeezed material. In this study, there were six grooves (i.e., n = 6)— the circular plate and the inner surface of final gear had three grooves each.

Equation (3.3) can be used to derive the frictional force ($\mu F_{\phi 14}$) of the plate of $\phi 14$[mm] using the measured torque results. We employed the experimental data of the preliminarily developed device (of diameter $\phi 14$ [mm]) for which the limit torque experiment was conducted by increasing the thickness of the shim rings. Therefore, the surface friction force of increasing shim rings' thickness would be derived from the load torque (from 1.1 to 2.7 [N·m]) corresponding to the shim ring of thickness ranging from 0 to 0.5 [mm]. However, the different diameters ($\phi 14$ and $\phi 18$ [mm]) of the circular plates are based on the same servo motor and the same material. Thus, it can be assumed that the two circular plates of different diameters are subjected to equal friction forces ($\mu F_{\phi 14} = \mu F_{\phi 18}$). The theoretical torque results are attained by substituting the frictional force ($\mu F_{\phi 18}$) into Eq.(3.3). Furthermore, Eq.(3.3) also considers the additional torque caused by the pressure of the lateral side because of the Poisson effect. This study is based on homogeneous and isotropic assumptions; therefore, we assume that the normal pressure (P_a) is equal to the pressure of the lateral side (P_s). The with grooves type produces additional torque caused by the local shear force from the squeezed material, as shown in Eq.(3.4). We assume that the global shear stress is induced by the friction force ($\mu F_{\phi 18}$); hence, the local shear force can be deduced as the product of the global shear stress and the projected area of the groove (A_g). Then, the additional torque is determined as the product of the local shear force and the equivalent radius. Finally, the delivered frictional torque of the device having grooves was obtained by using the delivered frictional torque of the without grooves type and the additional torque produced by the local shear force.

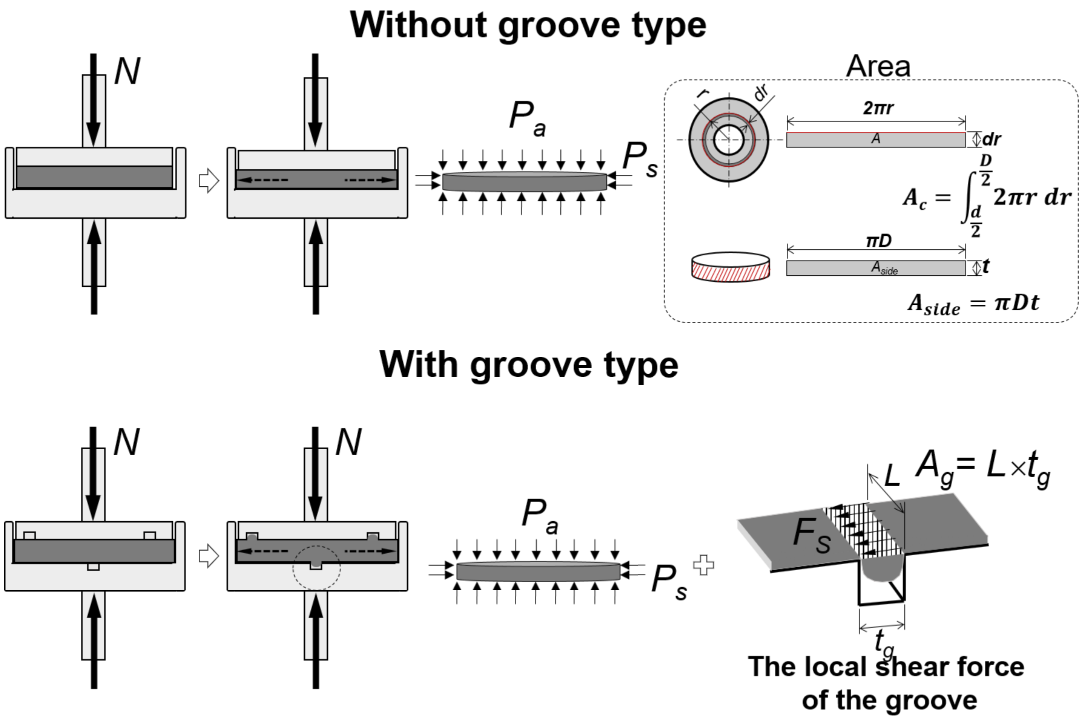


Figure 3.17. Forces on the circular contact surface.

3.5 Experiment and Results

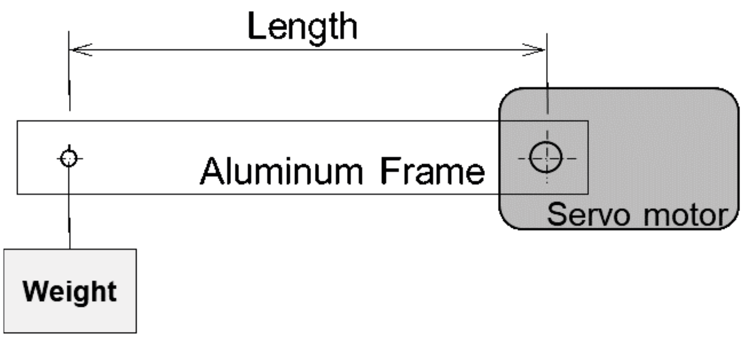
3.5.1 Limited Torque Experiment

In this study, it was necessary to be cautious while selecting the material for the hollow rubber circular plate because the endurance and delivered torque capacity were important factors for maintaining the service life of this device. Hence, we conducted an experiment to confirm the limit torque of this mechanism for the various kinds of rubbers. In our previous research [74], we compared the plates of different diameters ($\phi 14$ and $\phi 18$ [mm]) with eight rubbers that did not have grooves. To confirm the performance of this torque limiter mechanism, we improved the surface shape design (for with and without grooves type) of the final gear. In this experiment, we used a plate having a diameter of 18 [mm] for each of the with and without Grooves type. Furthermore, we used five materials to assess the limit torque of this torque limiter. Figure 3.18a shows the schematic of the experimental setup used to measure the torque. The torque limiter experiment was set up as follows: 1) The servo motor was set up at a specified angle by the program. 2) An aluminum frame was used to emulate the cantilever beam and acquire the torque by changing the weight and the length of the frame. Additionally, we prepared five materials for the experiment: NBR (nitril-butadiene rubber), CR (polychloroprene, normal and soft type), TPO (t (polyvinylchloride), Silicone rubber, Polyurethane rubber, and Polymer of styrene as shown in Fig. 3.18b.

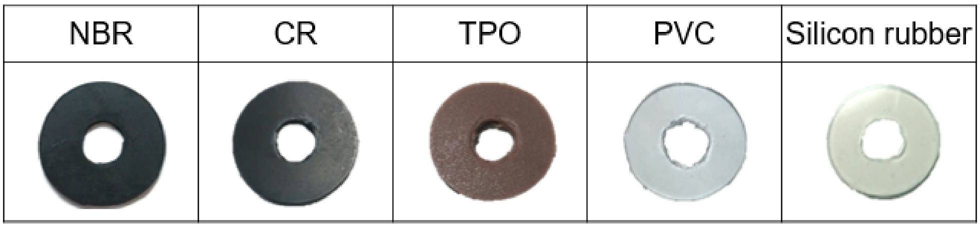
One of the important factors in the torque limiter mechanism is the normal force, which has a vital influence on the delivered torque. In this study, we attempted to increase the number of shim rings on the final gear, as shown in Fig. 3.15. By increasing the number of shim rings, the rubber circular plate of the final gear was forced to shift, and it was then subjected to the normal force. This experiment employed PVC and NBR to examine the load torque variation by increasing the number of shim rings for the gear without grooves type. The number of shim rings ranged from zero to five, and their thicknesses ranged from 0 to 0.5 [mm].

3.5.2 Results of Limited Torque

From the results of the torque measurements for $\phi 14$ [mm] [74], it was clear that the NBR material had the highest delivered torque (2.9 [N·m]) as compared with the other four materials because of the high friction coefficient. However, the low friction coefficient of silicone rubber could hardly provide the transmitted torque. When we compared the small circular plate ($\phi 14$ mm) with the large circular plate ($\phi 18$ [mm]), we found that the NBR had elevated the delivered



(a) Schematic of torque measurement experimental setup.



(b) Five materials used.

Figure 3.18. (a) Schematic of the torque measurement experiment setup; (b) Five materials used.

torque capability from 2.9 to 4 [N·m] (the rated output torque of the servo motor). Furthermore, when the rubber materials were placed in circular plates of diameters $\phi 18$ and $\phi 14$ [mm], the larger circular plate supplied a higher transmitted torque than the smaller circular plate. In the previous experiments, most of the materials cracked badly except for PVC and silicone rubber. Nevertheless, the torque limiter mechanism was considered for the assistive device so that a long service life could be maintained for at least over one year. The results indicated that the transmitted torque of the PVC plate was two-t

), polyurethane rubber, and the polymer of styrene) were destroyed when subjected to the limit torque. Therefore, we removed these materials and chose the remaining types of rubbers; we used an $\phi 18$ [mm] circular plate to perform subsequent torque limit experiments in this paper.

During the experiments, we found that the slipping phenomenon had two phases. In phase 1, when the torque was constant but the torque load was increased, the torque limiter mechanism started to slip, but the frame retained its position. In phase 2, when the torque was constant but the torque load exceeded the critical value, the frame started to slip. In the slipping state, the surface of the sandwich material supplied the maximum static friction force required to maintain the final position. Therefore, the frictional coefficient of this type of rubber material had a vital influence on this device. Figure 3.19 illustrates the results of the torque measurement for the with and without grooves type for five types of rubber materials. The findings demonstrate that the with grooves type had a higher torque capacity as compared with the without grooves type. Moreover, when comparing the five kinds of rubber materials, the NBR and CR materials were found to be better than the other materials. Although the CR material was able to provide good torque performance, it was not good for use in the assistive device because it was badly destroyed when subjected to sudden overload. As revealed in Fig. 3.26, the gear with grooves type along with the NBR material achieved a torque limit of 4.5 [N·m]; therefore, NBR was considered the ideal material for assistive devices. However, the with grooves type when used together with the shim made of PVC also had the features of a good limit torque (3.8 [N·m]), and it did not crack easily; therefore, PVC is also good material for use in a torque limiter.

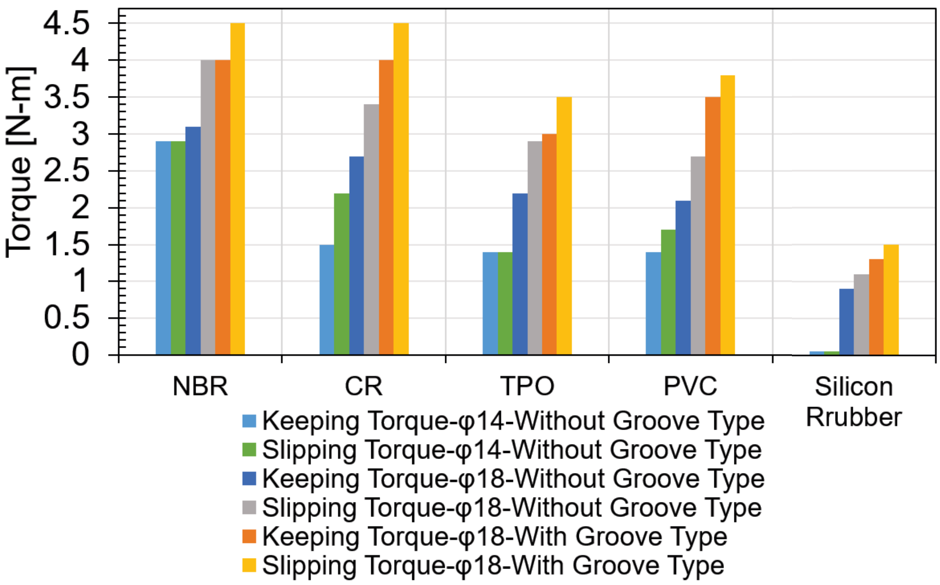


Figure 3.19. Torque measurement results for five materials used on two types of final gear designs (with and without grooves type).

The efficiency of the torque limiter (of diameter 18 [mm]) was verified by comparing the numerical calculation with the measured results. We made observations by increasing the thickness of the shim rings from 0 to 0.5 [mm]. Figure 3.20 shows a comparison of the calculated limit torque results with the measured limit torque results when the NBR material was used. For the without groove type, when the number of shim rings was increased, the measured limit torque increased from 2.3 to 4 [N·m] and the calculated limit torque increased from 1.82 to 4.47 [N·m]. The calculated limit torque of the with grooves type increased from 2.02 to 4.95 [N·m].

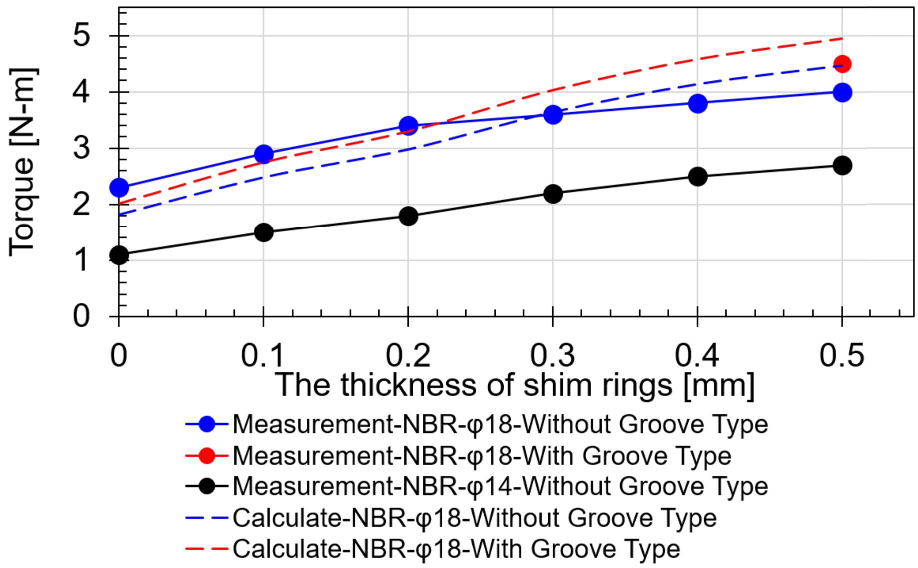


Figure 3.20. Comparison of the torque measurement with calculated torque results.

The results indicate that the theoretical calculation slightly underestimated the measured results when the thickness of shim rings were increased from 0 to 0.2 [mm]. The torque limiter was locked by artificial means, which could have induced an unstable locked force; therefore, the measured results were high. However, when the number of shim rings (with a thickness greater than 0.3 [mm]) was increased, the internal space of the motor was forced to enlarge the space; therefore, the motor might have caused a small deformation. Therefore, the measured results had a different linear tendency, and the theoretical calculation was slightly higher than the measured results. In general, the validation illustrates that the overall tendency is in good agreement with the torque measurement. By using our proposed torque equation, we found that the theoretical and measured results between the gears with grooves and the gears without grooves were almost the same. Therefore, the present theoretical torque equation is enough to predict the torque limit for the torque limiter.

3.5.3 Durability Experiment

To maintain the service life of this assistive device, we performed a durability experiment to examine the life of the rubber materials used in the with and without grooves type. The schematic of the durability test is shown in Fig. 3.21. In the durability test, the rubber material was subjected to cyclic load torques until failure (until the frame started going down). In the experimental

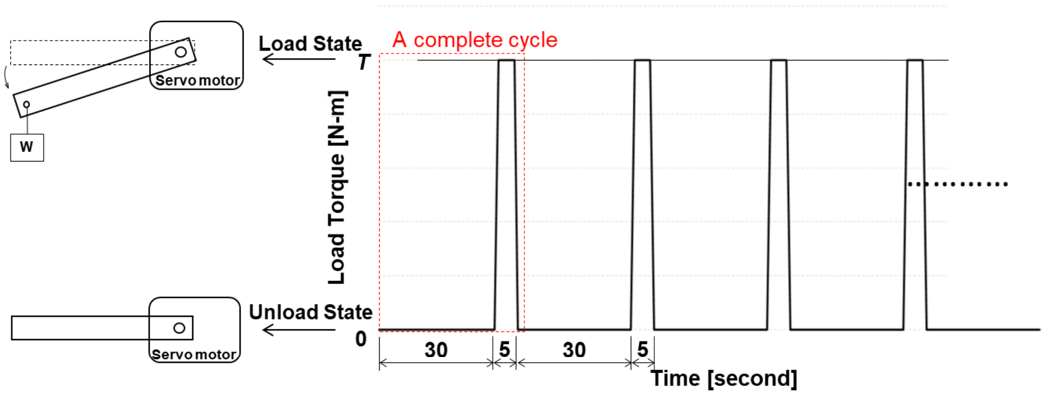


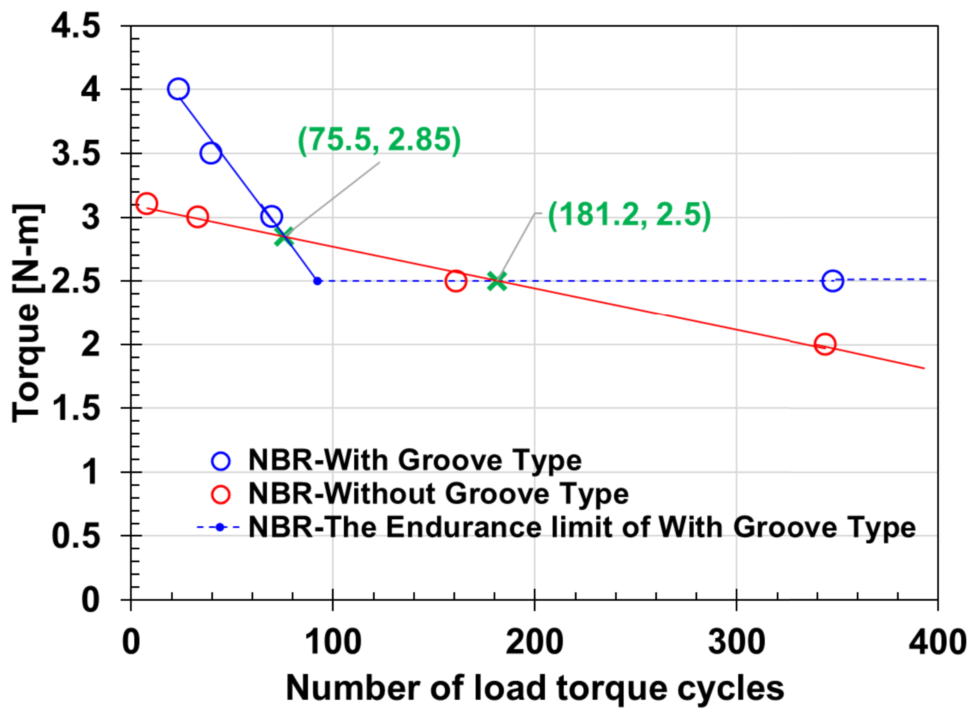
Figure 3.21. Durability experiment conditions of a complete cycle. The unloaded torque state was implemented for 30 [s], and then the loaded torque state was implemented for 5 [s].

conditions, we assumed that the person had overloaded twice in 1 min during continuous walking; this happens in real life when a person loses balance such as when stumbling or slipping. The experimental steps for a complete cycle are as follows: 1) Set the time interval to 30 s for unloading the torque state, and 2) After 30 [s], subject the rubber shim to the load for 5 [s]. Fur-
t

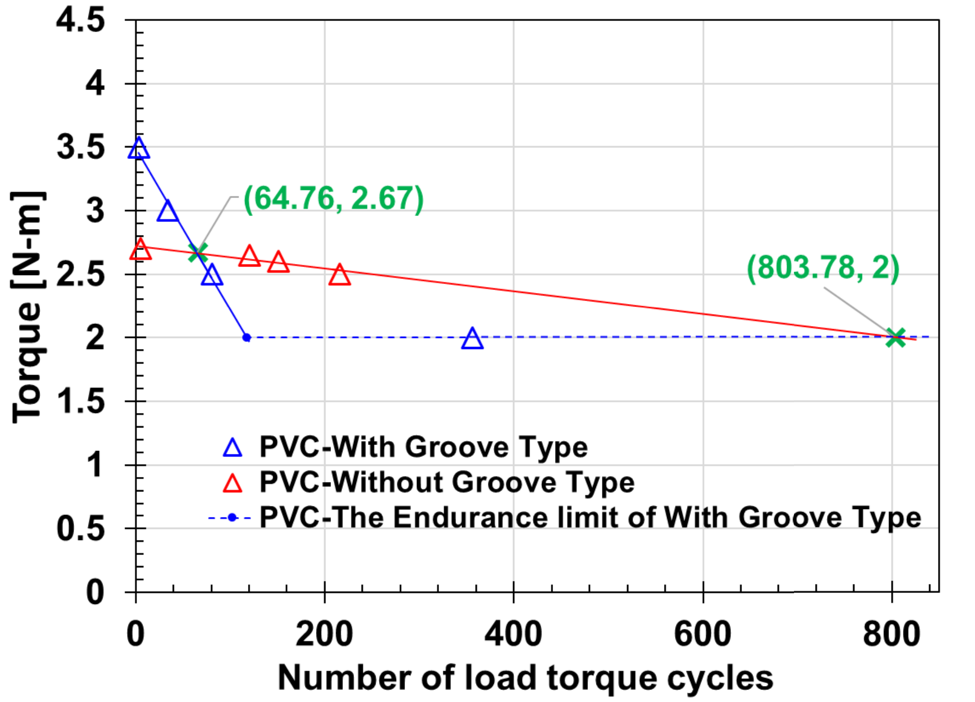
–N curve can then be obtained.

3.5.4 Results of Durability Experiment

Based on the results obtained in Section 3.5.2, we designated NBR and PVC as the main test materials. This study used the S–N curve to assess the durability of the two rubber materials in the with and without grooves type. Figure 3.22a illustrates S–N curves of NBR obtained by changing the two types of gear. The results of the S–N curves demonstrate that the two types of designs (with and without grooves type) exhibited different service life cycles. The blue line represents the torque for gears with grooves; it has a steep slope. However, the red line, which represents the torque for the without grooves type, shows a gentle slope. The two S–N curves have two intersection points at (75.5, 2.85) and (181.2, 2.5). These results show that when the NBR material was employed in the with grooves type, the subject's load torque was between 2.5 to 2.85 [N·m], and the service life was shorter than the that of the without grooves type, which used the NBR material. However, when the load torque was greater than 2.85 [N·m] or less than 2.5 [N·m], the with grooves type showed better service life than the without grooves type. Nevertheless, the S–N curves of the without grooves type show a very gentle slope, which also means excellent service life for the without grooves type. For instance, when the load torque was 2.6 [N·m], the service life cycles of the with grooves type was less than 100 cycles; conversely, the without grooves type produced more than 100 cycles. When the NBR material was used in the with grooves type, the S–N diagram becomes horizontal at 2.5 [N·m]. The load torque at this point is called the endurance limit, and it occurred at 92 cycles. Using the PVC material, we carried out the same durability experiments to compare the differences in the service life cycles of the with and without grooves type. As shown in Fig. 3.22b, the two S–N curves have two points of intersection at (64.76, 2.67) and (803.78, 2). Consequently, the results indicate that when the PVC material was used, the without grooves type had a better service life cycle than the with grooves type when the load torque applied was between 2.5 and 2.68 [N·m]. Nevertheless, when the load torque was greater than 2.68 [N·m] or less than 2.5 [N·m], the service life of the without grooves type was inferior to the service life of the with grooves type. Besides, when the PVC material was used in a with grooves type, the endurance limit occurred at 2 [N·m] and started at 117 cycles. However, the S–N diagram illustrates that it is difficult to obtain the endurance limits when using a without grooves type. Finally, a major finding is that the service life of the without grooves type is superior to the with grooves type only in the region of the intersection points of two S–N curves. In the rest of the regions, the durability of the with grooves type is better than that of the without grooves type regardless of the materials used. In case of an accident, any loss of balance would induce an unpredicted load. For instance, when there is any loss of balance, such as stumbling or slipping, the device can withstand the instantaneous load torque. The S–N curves indicate that the with grooves type can withstand low load torques (2.5 [N·m] for accident situations) over 300 times, and they can withstand high load torques (4 [N·m] for accident situation) approximately 24 times. The results reveal that the with grooves type can transmit a high torque; however, the without grooves type is better for long service life.



(**a**) S–N curves of NBR material.

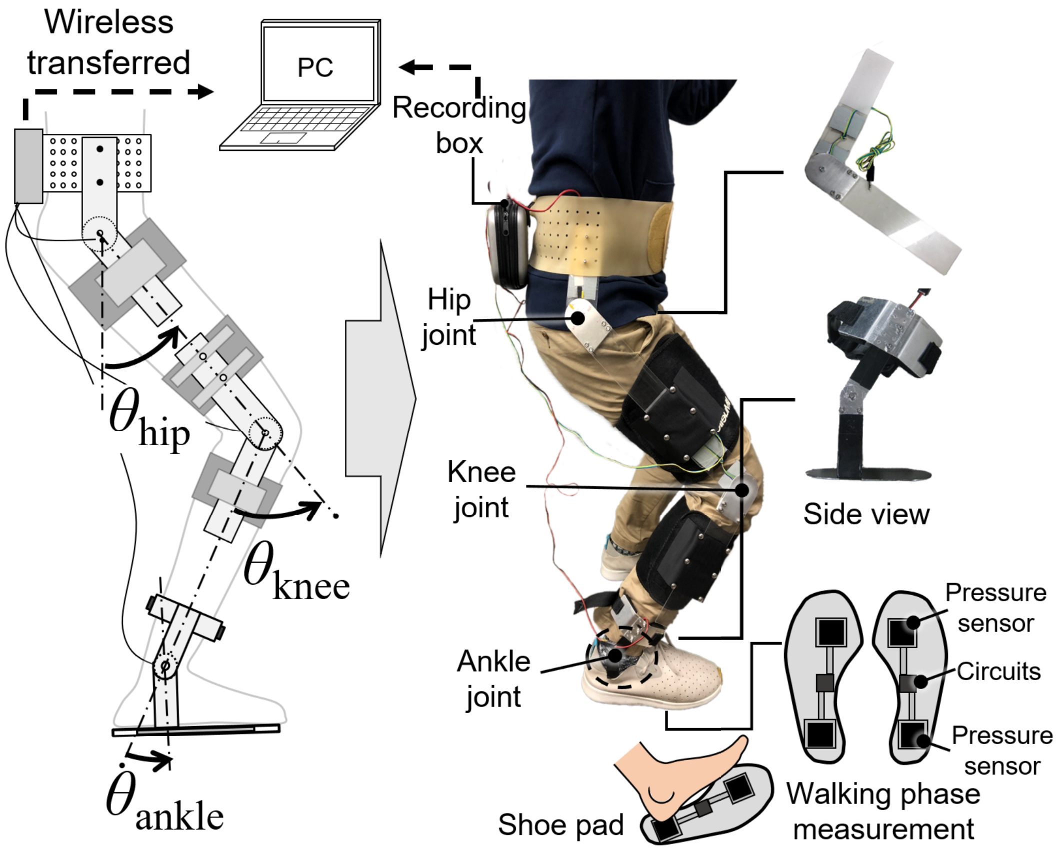


(**b**) S–N curves of PVC material.

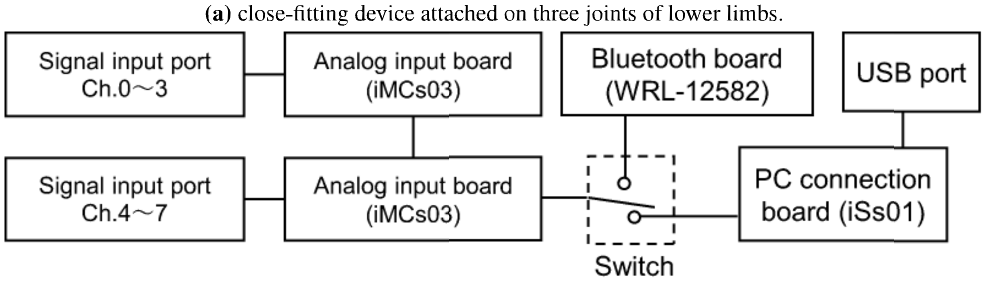
Figure 3.22. Comparison of durability results with two types of final gear designs.

3.5.5 Lower Limbs Motion Measured Devices

The joints of lower limbs of subjects were measured to further obtain the biomechanical information in walking. Figure 3.23 shows our developed joint angle measurement devices of lower limbs, which cooperated with iXs Co., Ltd. The devices employed the thin type potentiometers (RK14J11R000J) to acquire the analog signals and further to convert the angle signals (accuracy: ± 1.78 [deg]). These measurement devices were close-fitting to attach on three joints of lower limbs (hip, knee and ankle joints) to measure the angle variation of subjects, as shown in Fig. 3.23a. We made a recording box (as shown in the Fig. 3.23b) to collect the all measured data (angle variation and pressure value; sampling frequency= 20 [Hz]) t - sured data to the computer wirelessly in real-t . A recording box included two 10-bit analogs to digital converters (resolution: 5 [V]/ 1024 units) and a Bluetooth module. Moreover, according to the measured three joints angles, we could determine not only angle variation but also step length in walking. The step length could be obtained via following way: 1. defined hip joint as the original point (0,0) and obtained the data of the position (x_i, y_i) of the foot by each joint's angle variation. 2. by logging the data of the position $(x_{(i,i+1,...i+n)}, y_{(i,i+1,...i+n)})$ of the foot, the walking trajectory could be plotted and further the step length could be calculated. Besides, the pressure sensors were attached to the shoe pad to determine the walking phase of subjects in the experiment.



(**a**) close-fitting device attached on three joints of lower limbs.



(**b**) the system of the recording box.

Figure 3.23. The developed joint angle measurement devices of lower limbs, which cooperated with iXs Co., Ltd. [118].

3.5.6 Walking Experiment of the Torque Limiter applicability

The purpose of this experiment is to evaluate the applicability of the torque limiter in real walking. Thus, we mainly checked subjects' ankle motion for confirmation of the torque limiter can be used or not.

Protocol: The subjects were required to comfortably walk with device and without device for 5 minutes. 2 subjects (age:26, height:169 [cm], weight: 58 [kg]) joined this experiment. Walking scenario is shown in Fig. 3.24.

Task	1. **Without** device walking 2. **With** device walking
Conditions	**Comfortable speeds**
Time	Walking for 5 min

Subject: 2
Age: 26
Height: 169 cm
Weight: 58 kg

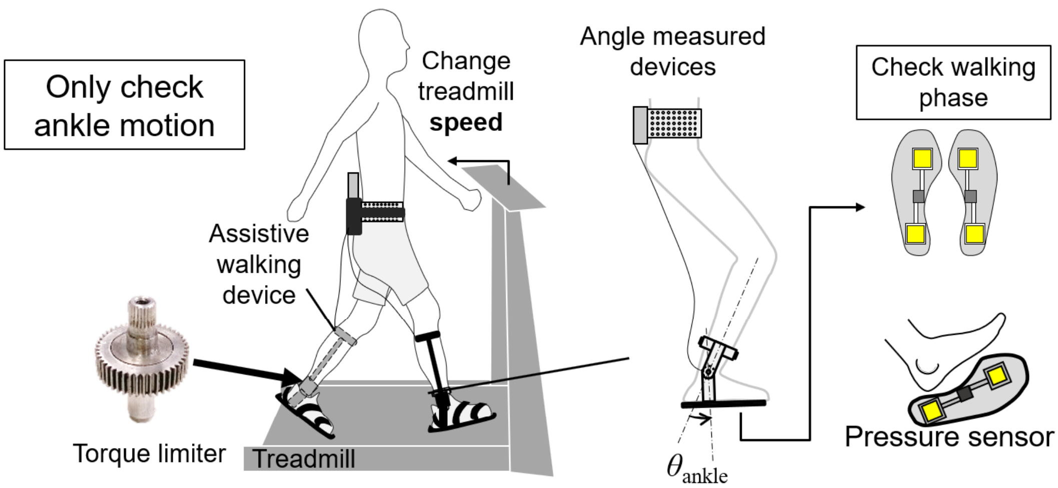


Figure 3.24. Walking experiment of the torque limiter applicability.

3.5.7 Results of Walking Experiment of the Torque Limiter Applicability

We confirmed the data of the entire ankle movement for the first five minutes to observe the user's suitability for the device as shown in Fig. 3.25. The results of the without wearing device indicated that the motion was unstable while walking. We observe that the subject 1 performed the plantar motion [-θ

It means the subject 1 attempted to raise their leg using push-off motion during walking. The young adults are usually using push-off motion that might increase the energy consumption and muscle would become easily fatigue (e.g., tibialis anterior and gastrocnemius muscle) during walking. With time passing, subject 1 found how to walk rather than only using push-off motion. Subject 1 was further gradually increasing the dorsiflexion motion and becoming normal walking motion during the middle period. From measured data of wearing device, we observe the ankle's angle of the user can be effectively controlled in each walking period. Our developed device can maintain the same gait and achieve the assistance of dorsiflexion; also, they can be guided to perform the correct angle of the ankle for the whole trial when using this device.

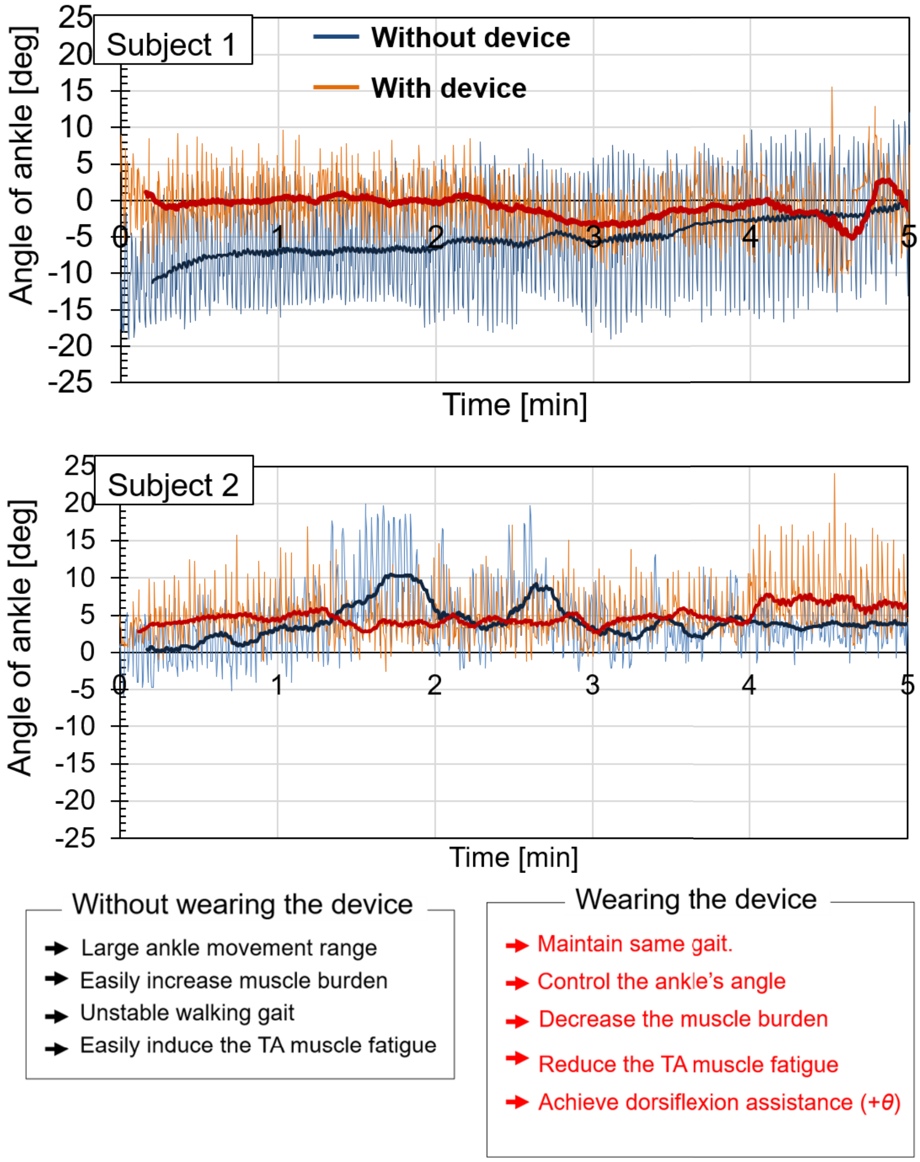


Figure 3.25. The ankle angle data in walking trial for an initial period of five minutes.

3.5.8 Walking Experiment of the Assisitive Walking Device Applicability

In this study, we aimed to assess the effectiveness of this assistive walking device when users used it. Three able-bodied persons (height: 175.3±7.6 [cm], weight: 71.7±6.9 [kg] and age: 23-27 years old) participated in this experiment. The purpose of the experiment is to make the user can use an assistive walking device in daily life. Hence, in daily life, there are two crucial factors: 1. Users walk comfortably; 2. Users can long time use an assistive walking device

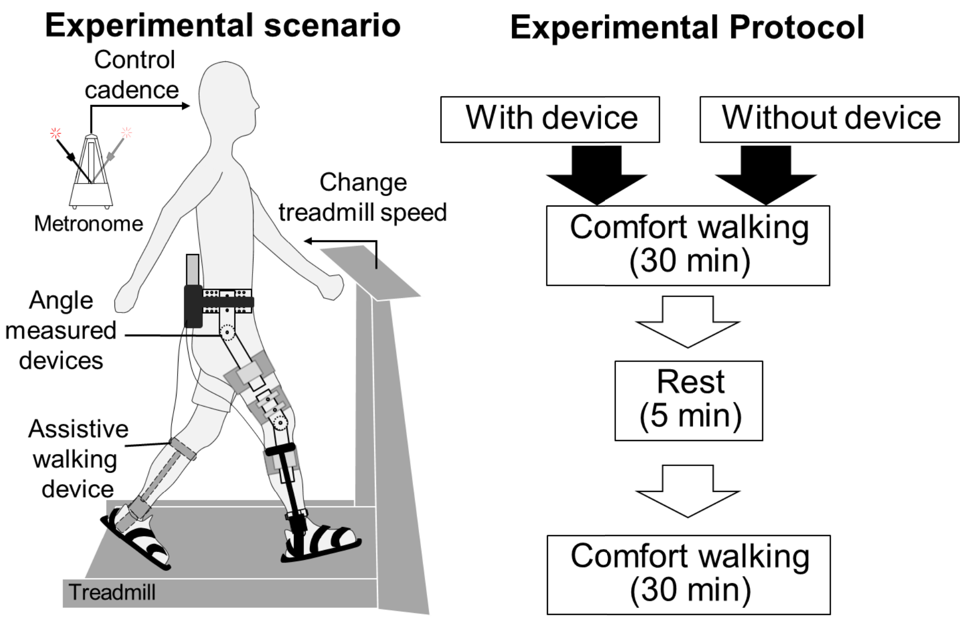


Figure 3.26. The experimental scenario and experimental protocol.

without reduction of the assistance effect. In this experiment, subjects walked on a treadmill under two conditions: (1) normal walking without the assistive walking device; (2) walking with the assistive walking device. Subjects walked at self-selected speeds and cadence under each condition for 60 minutes. Cadence was controlled by a metronome. In the experiment, subjects were required to follow the motion of device. Figure 3.26 shows the experimental scenario and experimental protocol.

All gait data were obtained from the developed measurement devices. For each experimental condition, three joints angle variation, dorsiflexion range, toe-off timing, step length, and walking ratio were calculated as gait data for comparisons in with and without wearing an assistive walking device. According to the walking time, we collected the gait data of five periods: 5, 15, 30, 45, 60 minutes. All gait data were averaged by collecting at least ten individual walking cycles, which began and ended with heel contact of the same foot, and then normalized in time by percent walking cycle (0-100%). These post-processing calculations were performed to produce gait data for each subject.

TABLE 3.3: Self-selected gait of each subject.

	Selected speed [km/hr]	Selected cadence [step/min]
Subject1	1.6	84
Subject2	1.5	63
Subject3	2.0	57

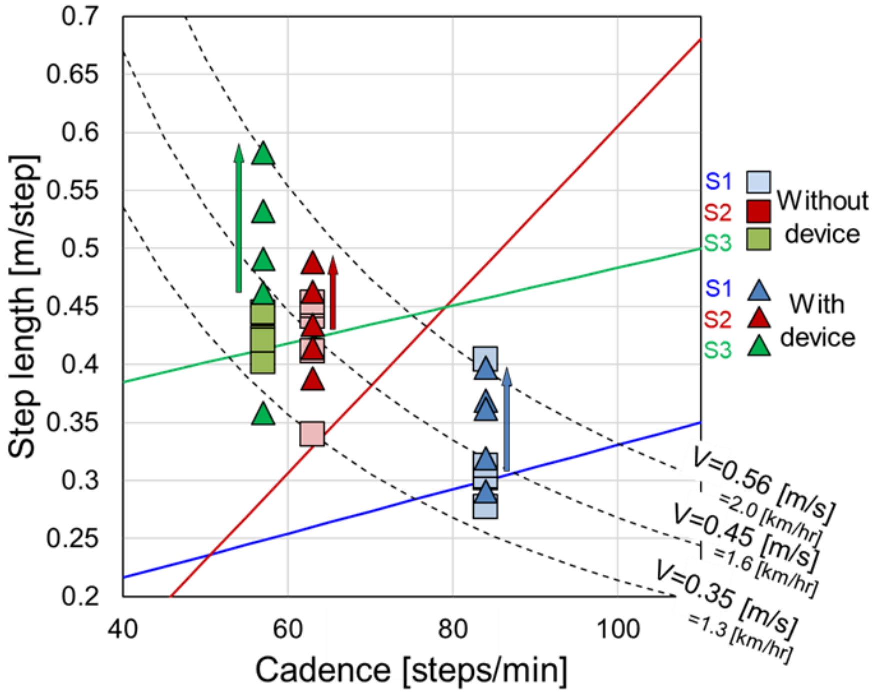


Figure 3.27. The 2D walking map of three subjects' experimental results.

3.5.9 Results of Walking Experiment of the Assisitive Walking Device Applicability

We compared the kinematic trajectories of with and without wearing an assistive walking device to show how the device affected the gait. Figure 3.28 exhibits the angle variation of each joint in with and without wearing an assistive walking device under 5, 15, 30, 45, and 60 [min], respectively. First, along with increasing walking time, the angle variation did not exhibit the obvious change. We further compared the averaged data in with and without wearing the device. Moreover, we found that toe-off timing delayed when walking without wearing the device. This indicated that the subjects' stance period was too long, which would force the foot movement to be faster to complete the walking cycle. Whereby, it is likely to cause the subjects to fall. However, compared to walking without the device, wearing the device could

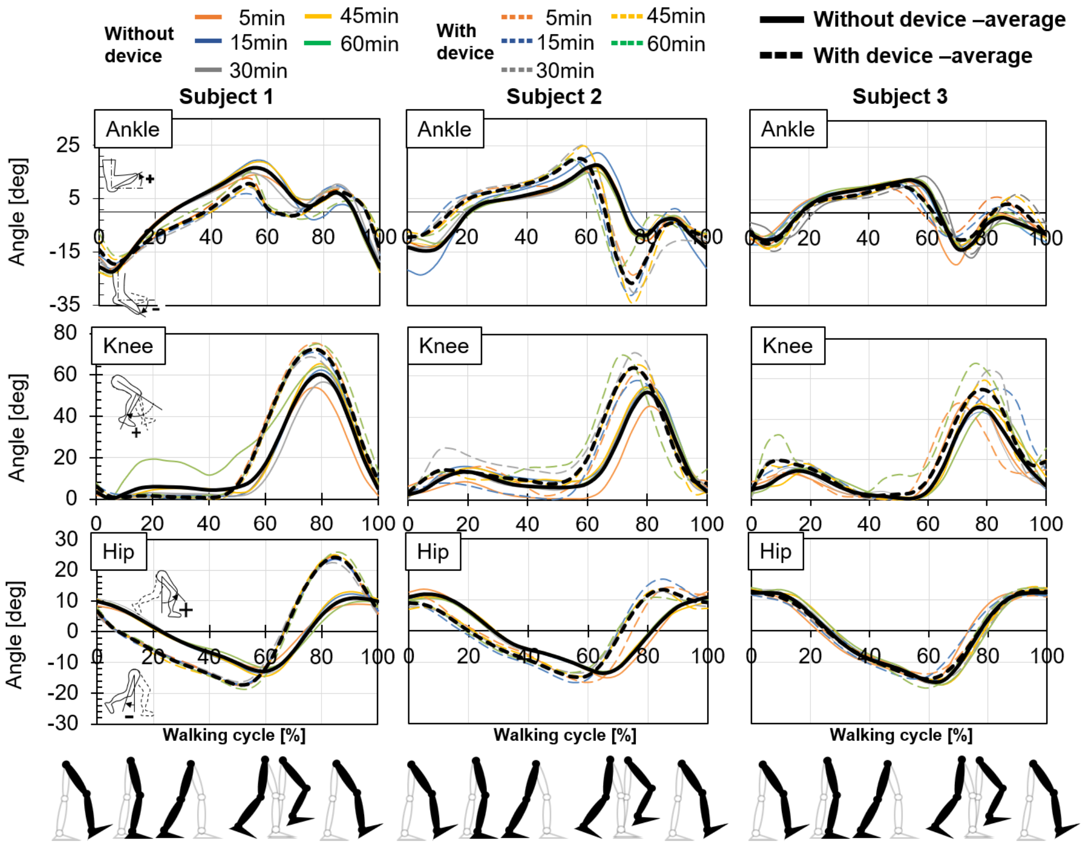


Figure 3.28. The angle variation of each joint in with and without wearing an assistive walking device. 5, 15, 30, 45, 60 minutes averaged results are indicated to compare the difference. Black color line shows the averaged data of with and without device walking.

relatively defer the occurrences of toe-off timing delayed, as shown in Fig. 3.28. In addition, during the toe-off phase to the swing phase, we found that the angle variation of each joint (hip flexion, knee flexion, and ankle dorsiflexion) increased while wearing the device. The kinematic changes showed that our assistive walking device could guide the subjects' lower limb to conduct the specified motion further to be achieved assistance. Moreover, we used a two-dimensional (2D) walking map [76] to further observe the walking ratio (walking ratio is the step length (S)[m/step] divided by the cadence (C) [step/min]) for comparisons in with and without wearing device. We would like to examine the influence on step length when wearing the device by using the 2D walking map. In this experiment, we required the subjects to follow the selected cadence to walk on the treadmill. We plotted the three subjects' step length and cadence at 5, 15, 30, 45, and 60 [min] on the 2D walking map, as shown in Fig. 3.27. Blue, red, and green line respectively indicate the walking ratio of each subject. The dashed line represents the walking speed, which is calculated by the formula of walking speed (V) [m/min] = step length (S) [m/steps]$\times$cadence (C)[steps/min]. When without wearing device walking, we found the step length of each subject did not exhibit the obvious change (square marker). On the contrary, when wearing device walking, the results showed the step length of each subject was increased (triangle marker), which also indicated the walking speed was boosted. The walking speed is dynamic even though the treadmill speed is constant. Thus, the reason why the speed would be boosted when the subjects selected the constant speed to walk. For the elderly with limited mobility, it is necessary to elevate the walking speed and step length during walking, which likely to enhance self-confidence further improve their quality of life. Hence, the walking behavior changes caused by our assistive walking device could achieve ideal walking performance. We plotted the toe trajectories while walking, as indicated in Fig. 3.29. Red color and blue color represent the with device walking and without device walking, respectively. The results exhibited that the subjects could elevate the height of the toe while walking wearing the device; whereby, we could ensure the heel contact to the ground would be happened at the end of the walking cycle. Thus, it also means that when using the device, the users can prevent stumble owing to inadequately the height of toe during walking.

3.6 Discussion

3.6.1 The Applicability of the Torque Limiter

The applicability of the torque limiter mechanism was confirmed by comparing the with grooves type with the without grooves type. Additionally, we examined the NBR and PVC materials for determining the delivered torque and the durability. As indicated above, the torque performance of the plate of ϕ18 [mm] was superior to that of ϕ14 [mm]. NBR and PVC were chosen as the primary assessment materials because they did not crack easily. Furthermore, we found that both designs had a vital influence on the delivered torque and on the durability. The results show that the with grooves type had excellent transmit torque performance appropriate for users requiring high assistive power, e.g., the elderly. Furthermore, the without grooves type had a long service life, which is required for healthy persons. On comparing the NBR material with the PVC material, the torque limit of NBR was found to be higher than that of PVC. The service life assessment shows that the NBR and PVC performances were roughly the same when the load torque applied was less than 2.5 [N$\cdot$m]. In this study, we suggested the use of a plate of ϕ18 [mm] for two designs with and without grooves by employing NBR material for the torque limiter. This successfully prevented the assistive device from damage when used for assistive functions. Finally, the developed torque limiter mechanism was assembled into the walking assistance device. Subjects confirmed that they could feel the difference when the device used the torque limiter. We tested the device by performing outdoor walking trial tests by allowing the subjects to wear the device and walk outdoors. The trial test included the following: 1) free walking (without wearing the apparatus), 2) walking while wearing the device without assembling the torque limiter into the walking assistance device, and 3) walking while wearing the device by assembling the torque limiter into the walking assistance device. The results showed that the ankle joint's target angle variation data were not changed. The subjects stated that incorporating the torque limiter in the device helped improve the gait and made them feel comfortable. The targeted angle variation data were designed only for walking on level ground; therefore, the assistive device could adapt to various road conditions using the slipping function of the torque limiter mechanism. Based on the same concept, the control method of this assistive device was used for the angle variation control instead of the angle control. From the subjects' feedback, it was clear that they felt that the assistive power increased by using the new torque limiter mechanism having plates with $\phi 18$ [mm] and grooves combined with the NBR material.

3.6.2 Effectiveness of an Assistive Device

We used the one-tail paired t-test to compare a significant change in with and without wearing an assistive walking device (significant level =0.05). The findings exhibited that the toe-off timing (normalized to the time) was improved significantly ($-5\%, p < 0.05$), as shown in Fig. 3.30 (a). These results represented the subjects could learn the correct gait performance during walking. By this evaluation for the elderly, it is able to effectively reduce the problem of delayed gait. The evaluation of the angle variation (ankle, knee, and hip) normalized to the range of 0 to 1. From the Fig. 3.30 (b), our assistive device could assist the ankle dorsiflexion motion significantly (+13 [deg],$+46.2\%, p < 0.05$); whereby, this result could resolve issues of the insufficient dorsiflexion angle for the elderly during walking. Moreover, from the Fig. 3.30 (c) (d), knee flexion (+3.3[deg],$+25.6\%$) and hip flexion (+2.3[deg],$+9.3\%$) motion also could improve the problem of insufficient foot- leaving-ground clearance further avoid the fall down. Step length values were normalized to the subjects' height as shown in Fig. 3.30 (e). We found that the step length could be assisted significantly (+6.7 [cm],$+8.8\%, p < 0.05$), which also could elevate the walking speed (walking speed [m/min] = step length [m/steps]$\times$cadence [steps/min]) to attain better walking performance. Consideration of the real scenario for promotion of walking exercise while wearing an assistive device, we expect that the users can walk comfortably for a long time. As indicated results, the subjects could walk at least one hour while wearing assistive device without decreasing of the assistance effect. Additionally, from the results and evaluation of Fig. 3.30, our device proved its effectiveness, which could correct the lower limbs walking motion of the subjects. It could improve the problem of insufficient foot-leaving- ground clearance for prevention of fall down. Moreover, subjects could naturally elevate the step length and walking speed. By evaluation, we believe that our assistive device can provide a suitable function for the elderly to promote the exercise and improve the quality of life. We will invite the elderly to be the subjects for future works.

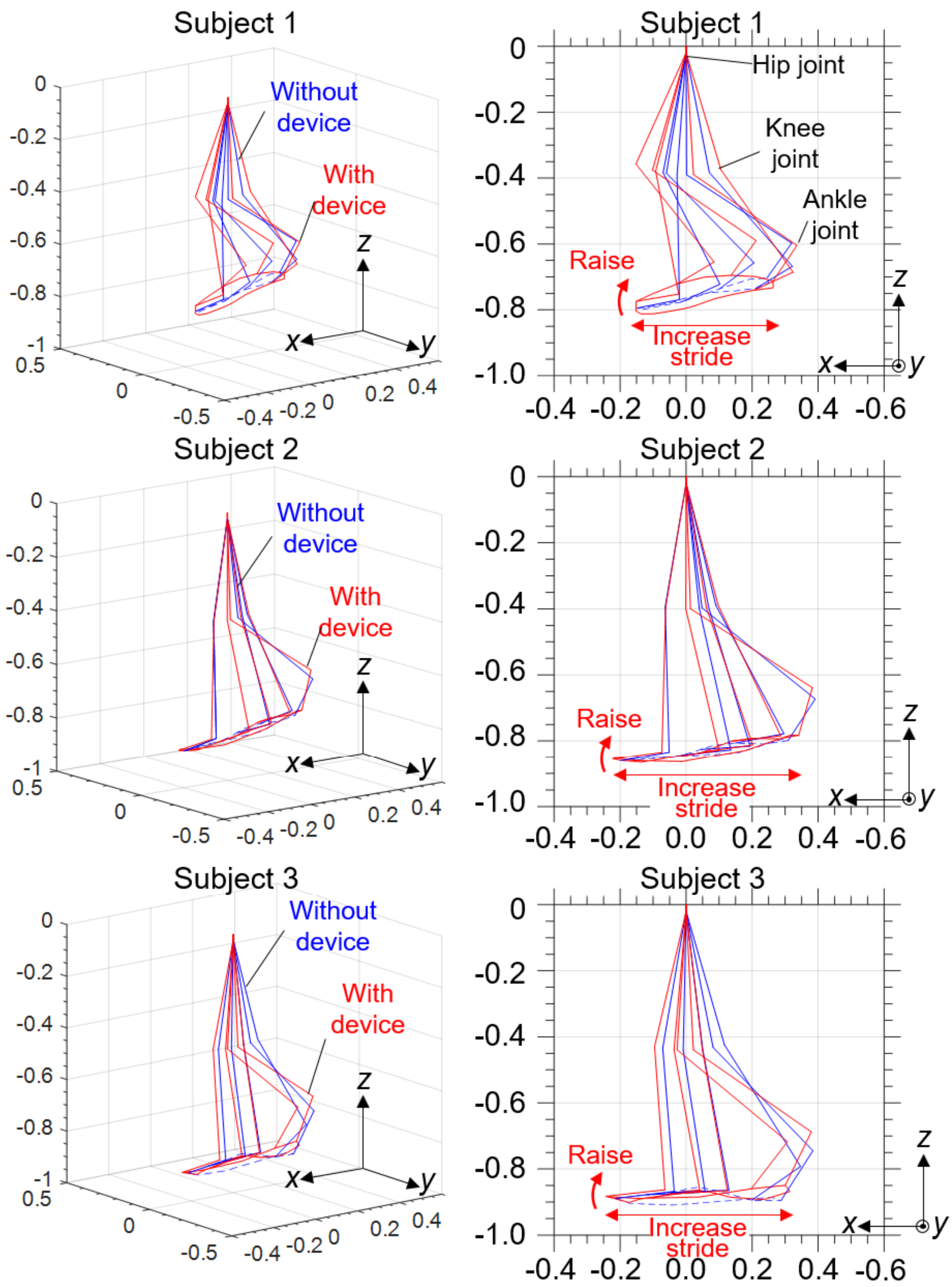


Figure 3.29. The averaged toe trajectories of three subjects walking for 60 minutes.

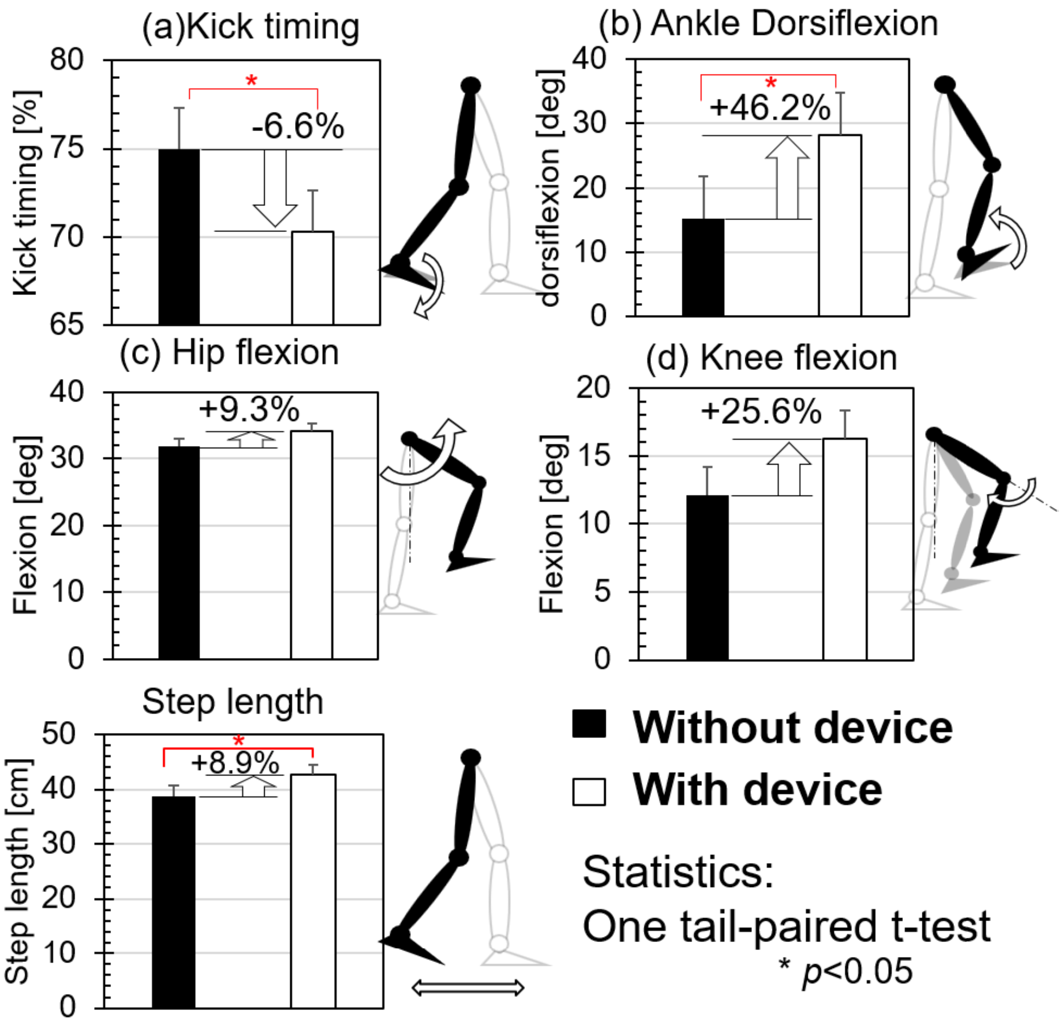


Figure 3.30. The evaluation of the gait kinematics in comparison to wearing and without wearing the device. (a) Toe-off timing (normalized to the time); (b) ankle dorsiflexion range; (c) hip flexion range; (d) knee flexion range; (e) step length change (normalized to the subjects' individual height and averaged height).

3.7 Conclusions

A small and lightweight device with a compact torque limiter is proposed for teaching correct timing and motion for the elderly to promote exercise. To promote the elderly's body condition by exercise, the device should be designed as small as possible. The device thus used a compact hobby servo motor. Currently, to make a very compact motor, the safety factor would be designed to close to 1. However, the device easily encounters unexpected overloads that lead to a gear broken in the motor. For the prevention of breakage, a compact torque limiter was designed in a gear of motor, which maintains the same size and weight as the original gear. The torque limiter configured a rubber between a pair of circular plates. Rubbers thus play a vital role. The torque and durability tests verified the effectiveness of torque limiter. The results showed the torque limiter together with NBR rubber can reach the rated torque (4 N-m) of motor and respond well to the unexpected load torque at least 300 times (1 exercise/ day for 30 min encounters 1 accident. It can be used for 10 months.) for continuous accidents. Next, to confirm the effectiveness of this device, the gait data of the users were evaluated in comparison to wearing a device and without wearing a device. The results proved when the device was used, it can significantly improve the dorsiflexion motion (+13 [deg/hour], +46%), the kicking timing (-7%/hour), and the step length (+7 [cm/hour], +9%). Thus, the device can promote exercise in the elderly.

Chapter 4

Real-Time Emotion Recognition System with Multiple Physiological Signals *

4.1 Abstract

Emotion is an internal and subjective experience that plays a significant role in human life. There are several methods of recognizing emotions in people, the most authentic of which is using physiological signals, as they are beyond one's control and strongly correlated with human emotions. This study aims to develop an emotion recognition system based on three physiological signals, namely, brainwave, heartbeat, and facial muscular activity. It utilizes deep neural network (DNN) and the T method of Mahalanobis-Taguchi system (MTS) to process the multiple physiological signals and further recognize the states of human emotion. As such, nine emotions are effectively recognized on a two-dimensional model through the DNN, then compared against several other algorithms, such as MTS, SVM, Naive Bayes, and K-means, where its superior accuracy is validated. Moreover, although the T method only improves the classification accuracy on the valence state, it rather obtains the intensity of emotion in different states. Furthermore, in this study, the proposed DNN is implemented into a wide range of applications for an accurate understanding of the human emotional states, whereas the T method is utilized to respond to the emotional intensity in different states. Finally, a real-t

*This chapter's contents relate to the published journal paper: Zhuang, J.R., "Real-T

. 13, Issue 4, (2019), Paper No.19-00212 (16 pages) Indicated in research achievement of journal[1]; reference[134] signals. Thus, the method can provide useful treatment effect information for robots or assistive apparatus serving activities of daily living [134].

4.2 Introduction

Emotion recognition is a key technology of human-computer interaction. Recent studies on recognizing emotions have extensively focused on facial expressions, speech, posture, and physiological signals [46], but since understanding and expression of emotions promote interpersonal communication, human–computer interaction methods that pay attention to the user's emotional information are more suitable. Emotion recognition based on physiological signals has significantly different characteristics compared with that utilizing speech-and-image elements; thus, the former method becomes an important direction in the field of affective computing [47]. Psychology and physiology provide evidences of strong correlation existing between physiological responses and human emotional states. For instance, the physiological signal is directly controlled by the autonomic nervous system and is not subjectively influenced by the subject; therefore, the recognition result becomes more realistic and objective [48]. Through measuring electrocardiogram (ECG), the arousal emotion could be assessed by the ratio of sympathetic value and parasympathetic value (Tanaka et al., 2017). Agrafioti et al. (2012) [50] devoted to analyzing the ECG pattern to determine the arousal state for emotion recognition. In addition, facial elec-
t

[54] proposed a framework to process EEG-based emotion recognition. Studying EEG is valid for comprehending the human emotion. Generally, previous studies used a single physiological signal for judging emotion and ignored the fact that different emotional states may trigger multiple physiological signals, through which a fusion analysis may more accurately identify specific emotional states. Emotion recognition technique is useful to various fields. Especially, during the rehabilitation, it is necessary to understand patients' mental state, which may provide medical staff to know their current condition further give mental assistance to patients. In chapter 2, we focused on developing an

assistive walking device for hemiplegic patients and the elderly due to muscle weakness. The device can drive the joint in the ankle to trigger stretch reflex mechanism and further raise the user's leg via a muscle linkage effect to prevent them from stumbling. Nevertheless, from the viewpoint of rehabilitation, the patients' physical and mental aspects should be considered. Rehabilitation is a long-term and difficult work, and the patients are required to maintain their mental states for completion of the tasks involved. In other words, the mental states of the users are taken into account prior to using the assistive device for rehabilitation [77]. Moreover, our previous studies applied the beat sounds to investigate the emotional variation of human in walking [78] at first. Afterward, we used the clustering algorithm to analyze the physiological signals mapping on the two-dimensional (2D) emotion map [79] and attempted to control the assistive walking device using the users' heartbeat signals [49]. To recognize emotion precisely, we introduced DNNs to classify the multiple physiological signals, along with an answered questionnaire, and then identified nine emotional states on a 2D emotion map [80]. The study of the application of emotional recognition has been proposed in recent years. Kolakowska et al. proposed the emotion applications for software engineering [103]; Kim et al. used a stimuli control system to adjust group emotion such as kindergarten [104]. Very limited studies mentioned the emotion-control applications for human rehabilitation.

4.3 Purpose

The existed emotion recognition systems had problems of only a few states prediction and using outer physiological signals (such as voice and facial motion) that are faked easily led to inaccurate recognition. To raise the accuracy, multiple emotion states recognition system with inner physiological signals is needed to propose. This chapter aims to develop such emotion recognition system that is based on the analysis of multiple physiological signals, extracted via emotional stimuli experiments, and apply the proposed classification algorithms to accurately realize the states of human emotion on an arousal–valence plane. Our final goal is to employ this emotion recognition system to real life for offering beneficial in various fields.

4.4 Related Work

Figure 4.1 [81] describes a 2D emotion model using two indicators, valence and arousal, of emotional state measurement. Valence is represented by the horizontal axis, which is divided into two types of emotions: positive and negative. Positive emotions refer to feelings that are pleasant, i.e., happy and contented, whereas negative emotions include unpleasant feelings, i.e., sad, upset, etc. On the other hand, arousal is indicated by the vertical axis and reflects the intensity of the emotions.

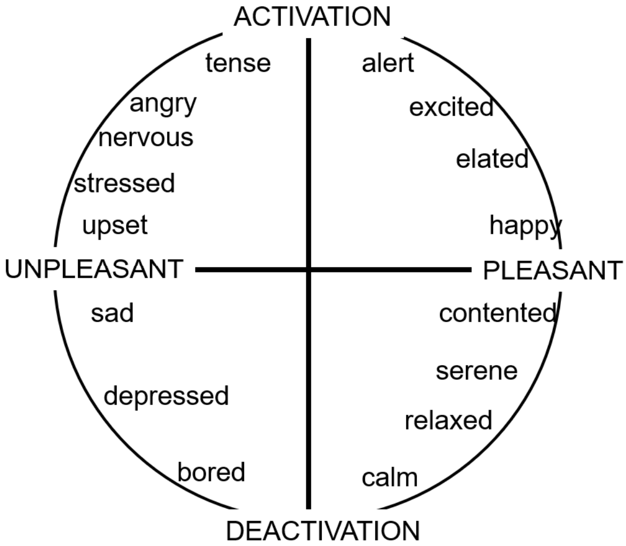


Figure 4.1. A two-dimensional emotion model [81].

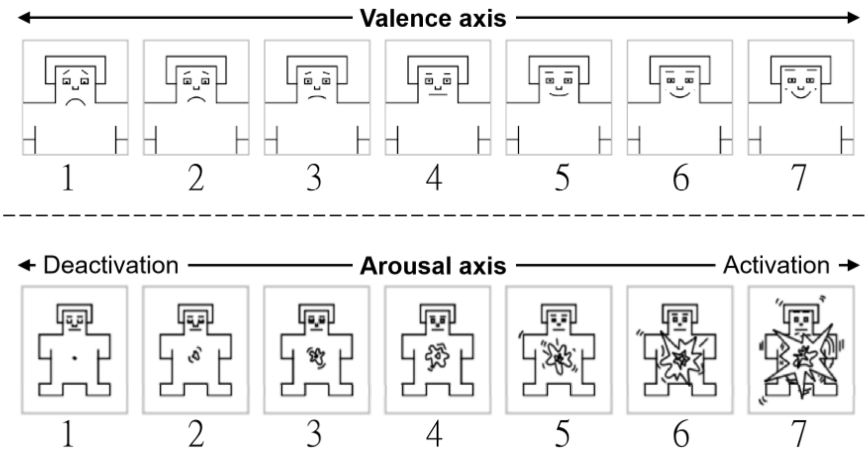


Figure 4.2. Self-Assessment Manikin (SAM) [82].

Imprecise understanding of words in conventional studies has often led to wrong description of emotions. Bradley and Lang (1994) [82] attempted to solve this problem by designing a picture tool called Self-Assessment Manikin (SAM) to directly evaluate pleasure and arousal. SAM is mainly characterized by a nonverbal pictorial assessment, that is, it uses simple figures to describe the dimensions of the emotion model. Moreover, SAM representative expressions

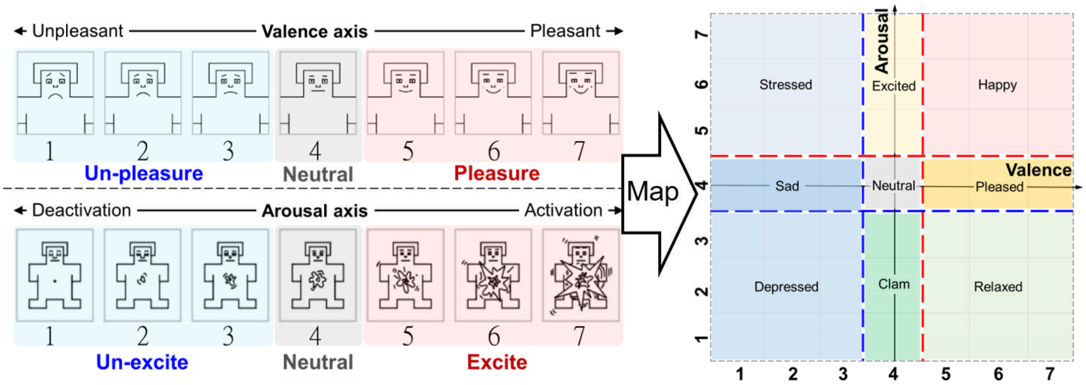


Figure 4.3. Nine states of the 2D emotion model.

provide a range of dimensions from smiling to frowning (pleasure) and from excited to relaxed (a In our experiment, we presented a level 1–7 scale for both dimensions, as shown in Fig. 4.2.

Methods of emotion recognition based on physiological signals analyze the autonomic and central nervous systems. Recognition based on the autonomic nervous system identifies the corresponding emotional states through measurement of physiological signals, such as heart rate, skin impedance, electromyography, and respiration [83]. On the other hand, recognition based on the central nervous system analyzes signals generated by the brain under different emotional states [84-86]. Emotion is recognized through changes in the physiological signals using both methods and cannot be hidden; thus, we can get objective results. This paper considered the measurement of three physiological signals, namely, heartbeat, brainwave, and facial muscle activity.

4.4.1 Definition of the 2D Emotion Model

Three levels of valence and arousal states were mapped as follows. For the valence scales: 1–3 (un-pleasure), 4 (neutral), and 5–7 (pleasure). For the arousal scales: 1–3 (un-excite), 4 (neutral), and 5–7 (excite). Figure 4.3 enumerates the obtained nine emotional states: happy, pleased, relaxed, excited, neutral, calm, stressed, sad, and depressed.

4.4.2 Feature Extraction

We employed the mean and maximum values of the generated physiological signals as the features represent the physiological level of the emotion data from the experiment, as we proved these parameters to be more sensitive than the other values in our previous experiences. All the features were calculated from the raw physiological data, which were collected while the subjects watched the specific film clips. Table 4.1 presents the 17 extracted features, processed by the raw data of three physiological signals (EMG (Electromyography), HRV (Heart Rate Variability), and EEG(Electroencephalography)).

In the EMG data, we employed the (1) iEMG (integrated Electromyography) can indicate the state of muscle activities in real-time. It is suitable to be used as a quantitative analysis to determine the strength of muscle activity. (2) MVC (Maximal Voluntary Contraction) reflects the maximum strength which can be found the value from the iEMG [124]. After that, by using iEMG divided by MVC, %MVC can be achieved. It can be used for understanding the percentage of muscle activities. Also, MVC normalization is a regular method of amplitude analysis for analyzing the EMG data. The post-processing method applies the maximum root mean square (RMS) value. Through this normalization, we can eliminate the individual difference for comparison of different subjects. The unit of iEMG and MVC is voltage. The calculation of iEMG can be expressed in Eq. 4.1.

$$iEMG = \sum_{i=1}^{N} |X_i| \tag{4.1}$$

where X_i is the value of EMG signals. N is length of EMG signal samples. i is EMG signal in time segment i.

In the HRV data [123], we used the (1) Heart rate represents the number of beats per minute. Using the heart rate can understand the physical activity, threats to safety, and emotion. (2) LF/HF ratio which is employed to assess the emotional arousal. LF is an abbreviation for low frequency power (0.04 and 0.15 Hz) which has a in connection with sympathetic component (if LF value high, it means people feel stress); HF is an abbreviation for high frequency power (0.15 and 0.4 Hz) which reflect cardiac parasympathetic nerve's activity (if HF value high, it means people feel relaxation). LF and HF value's (power) unit is ms^2/Hz. The power of LF and HF can be expressed by Eq. 4.2 and 4.3.

$$LF = \int_{0.04}^{0.15} F_{hrv} df \tag{4.2}$$

$$HF = \int_{0.15}^{0.4} F_{hrv} df \tag{4.3}$$

where F_{hrv} is the HRV value in the frequency domain after using Discrete Fourier Transform. LF and HF can be calculated respectively by corresponding their frequency band (df means frequency element in frequency domain).

In the EEG, we utilized the band power of brainwave [122]: (1)θ wave (4-8 Hz) can indicate the relaxation, creative states and memory recalls. (2)α wave(8-12 Hz) is affected by eye closure. When open, high α value is observed. Usually, α wave indicates the static state of the brain such as relaxation and alertness. (3)β wave (12-25Hz) activities often relates to positive, task-oriented, busy or anxious thinking and positive concentration. It can be divided into two frequency of high β wave (18-25Hz) and low β wave (12-18Hz), which can make better understand the different condition. (4)γ wave(over 25Hz)is observe when human conduct strict cognitive or motor functions. During conducting multiple tasks, γ value increases. The unit of brainwave band power is uV^2/Hz. Also, it can be represents the form of decibels (dB) by taking $\frac{1}{20}\log_{10}(B$

.

B

. Therefore, the physiological baseline signal measured at the initial recording period was utilized to eliminate the effect of individual differences on the experimental results. Thus, the 17 extracted features were calculated by dividing the raw physiological signals with the baseline signal to obtain sample data for individual differences.

4.4.3 Evaluate Dataset

We collected the experimental data to determine the correlation between emotion and physiological signals, rather than to obtain the precise emotion elicited in response to a specific stimulus. Hence, it did not matter whether the response emotion did not match the expected emotion. In

T .1: Extracted physiological features.

Physiological data	Raw features	Extracted features
Facial EMG	iEMG,MVC	1. Maximum iEMG divided by MVC of the corrugator muscle (C.M.)
		2. Maximum iEMG of the corrugator muscle (C.M.)
		3. Maximum iEMG divided by MVC of zygomatic muscle (Z.M.)
		4. Maximum iEMG of zygomatic muscle (Z.M.)
HRV	Heart rate,LF/ HF	5. Maximum LF/HF
		6. Maximum variance of LF/HF
		7. Maximum heart rate
		8. Minimum variance of LF/HF
		9. Mean value of LF/HF
		10. Mean variance value of LF/HF
		11. Standardized (Std.) LF/HF
		12. Standardized (Std.) heart rate
EEG	Theta (θ_B) wave, Alpha (α_B) wave, Beta (β_B) wave, Gamma (γ_B) wave	13. Mean theta (θ_B) wave's power spectrum (P. S.)
		14. Mean α_B wave's power spectrum (P. S.)
		15. Mean θ_B wave's power spectrum (P. S.)
		16. Mean θ_B wave's power spectrum (P. S.)
		17. Mean γ_B wave's power spectrum (P. S.)

general, human emotions are dynamic, due to different environmental factors, including culture, nationality, and memory. The same stimulus may elicit different emotions in different people (or even to the same person) or situations. We compared the actual emotional states (based on the questionnaire results) with those from the database, as shown in Fig. 4.4. In the right side of the figure, the actual emotions were generally close to the selected emotion stimuli area; nevertheless, with respect to personal independence, the same emotions could be felt in different stimuli. For example, after the subjects watched the films eliciting excited and un-pleasure (solid red circle) emotions, some subjects had responses close to those on the database, whereas others gave different feedback. As the factual basis of this study, the actual emotional responses of the subjects were used. After the emotion elicitation experiment, all actual emotional responses would follow our emotion definition (in Section 4.4.1) to as emotion label. After that, we used the emotional label to correspond to physiological data (17 extracted features indicated in Section 4.4.2). From the mentioned steps, we created the 20 subject's physiological signal-emotion dataset.

4.4.4 Feature Selection

We selected a valid amount of physiological data from the experimental results and removed redundant information to prevent data noise from greatly reducing the accuracy of our data classification. In the process, we proposed feature selection to improve both the recognition result and the efficiency of the classifier and obtain only the valid features. In principle, feature selection extracts only the most effective of the features available as different types carry different signal

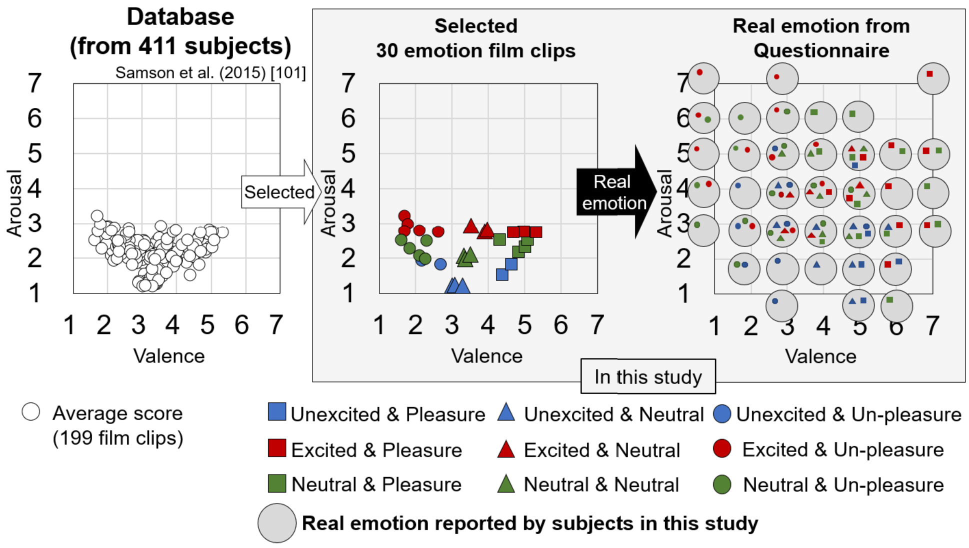


Figure 4.4. Actual emotional responses of subjects against expected emotions on the database.

TABLE 4.2: Selected physiological features on two emotional states.

Valence axis			Arousal axis		
Rank attributes	Extracted features	USE	Rank attributes	Extracted features	USE
0.3292	15. Mean low β P.S.	○	0.3562	10. Mean variance value of LF/HF	○
0.2452	14. Mean α P.S.	○	0.2629	6. Max. variance of LF/HF	○
0.2105	2. Max. iEMG of the C.M.	○	0.2357	5. Max. value of LF/HF	○
0.2034	16. Mean high β P.S.	○	0.2319	13. Mean θ P.S.	○
0.1696	13. Mean θ P.S.	○	0.1602	11. Std. LF/HF	○
0.1361	1. Max. iEMG/MVC of the C.M.	○	0.1531	15. Mean low β P.S.	○
0.1315	4. Max. iEMG of the Z.M.	○	0.1316	14. Mean α P.S.	○
0.1283	17. Mean γ P.S.	○	0.0923	16. Mean high β P.S.	○
0.0999	3. Max. iEMG/MVC of the Z.M.	○	0.0651	7. Max. heart rate	○
0	12. Std. heart rate	×	0.0614	17. Mean γ P.S.	○
0	11. Std. LF/HF	×	0.0554	9. Mean value of LF/HF	○
0	10. Mean variance value of LF/HF	×	0	2. Max. iEMG of the C.M.	×
0	9. Mean value of LF/HF	×	0	12. Std. heart rate	×
0	5. Max. value of LF/HF	×	0	3. Max. iEMG/MVC of the Z.M.	×
0	6. Max. variance of LF/HF	×	0	4. Max. iEMG of the Z.M.	×
0	7. Max. heart rate	×	0	1. Max. iEMG/MVC of the C.M.	×
0	8. Min. variance of LF/HF	×	0	8. Min. variance of LF/HF	×

information. For example, some features may express one's emotions more clearly, whereas others may contain invalid information. After selection, we individually analyzed the valence and arousal emotions; thereby, we had two classifiers.

Moreover, we utilized the information gain ratio, a statistical method that employs entropy to evaluate the worth of an attribute by the measured gain ratio [87] for this study.

Calculation of information gain ratio should start from understanding the entropy and conditional entropy. In information theory and statistics, entropy is a measurement of the uncertainty of a random variable. Conditional entropy can be explained as: The amount of information obtained when another piece of information is obtained based on certain information. The formula for computing the entropy and conditional entropy is respectively indicated in Eq. 4.5 and Eq. 4.6.

$$Entropy(E) = -\sum_{i=1}^{v} P(e_i) \log P(e_i) \tag{4.5}$$

i is the numbers of sets. $v \in$ R and $v > 0$. $P(e_i)$ represents the probability in each set (e_i).

$$CondEntropy(E|T) = \sum_{i=1}^{v} P(t_i) Entropy(E|T = t_i) \tag{4.6}$$

$CondEntropy(E|T)$ means conditional entropy of the features T on the set E (when given T condition, the uncertainty of the random variable E.

Information gain ($Gain(E, T)$)is the difference between the entropy $Entropy(E)$ and the conditional entropy $CondEntropy(E|T)$, which indicated in Eq. 4.7.

$$Gain(E, T) = Entropy(E) - CondEntropy(E|T) \tag{4.7}$$

The information gain ($Gain(E, T)$) indicates: the degree of uncertainty reduction of feature T to set E. Greater information gain indicates that feature possesses a higher ability to reduce the degree of uncertainty. Thus, we can confirm the feature T that is significant or not in the set E. However, if some data is not repeatedly, it induces the conditional entropy very small further leads to the value of information gain very large. Thus, it is easy to lead the algorithm to fall into a situation of local optimization further impact the globally optimal results. Thus, we should concern the intrinsic information of a split, which calculation is expressed in Eq. 4.8.

$$IntI(E, T) = -\sum_{i=1}^{v} \frac{|E_i|}{E} \log \frac{|E}{E} \tag{4.8}$$

Through considering intrinsic information, it can decrease the impact of the number of values on the validity evaluation of the attribute, then avoid a situation of local optimization. Gain ratio is a ratio of the information gain and intrinsic information. The calculation of gain ratio is expressed by Eq. 4.9.

$$Gainratio(E|T) = \frac{Gain(E, T)}{IntI(E, T)} \tag{4.9}$$

Gain ratio considers number and size of branches when selecting an attribute, and corrects the information gain by considering the intrinsic information of a split (for example, how much information do we need to tell which branch an instance belongs to)[116][117]. Figure 4.5

illustrated the example of using the method of gain ratio applying to this emotion recognition system for feature selection.

Table 4.2 breaks down the selected physiological features of the two emotional states. We selected the valid features according to the rank attributes calculated via the gain ratio; hence, we were able to trim down the number of extracted features for both states. The extracted features for the valence axis went down from 17 to 9 and from 17 to 11 for the arousal axis.

Example

Set E (Emotion columns); Set T (Physiological signals rows)

		Emotion: Pleasure (5,6,7)	Normal (4)	Unpleasure (1,2,3)	Total
Physiological signals	LF/HF	3	2	5	10
	α wave	4	0	4	8
	iemg	2	0	5	7
Total		9	2	14	25

The numbers of people's "LF/HF data" corresponding to the "unpleasure emotion"

① Entropy of selected these emotion

Entropy (E)

	Emotion: Pleasure (5,6,7)	Normal (4)	Unpleasure (1,2,3)	Total
Total	9	2	14	25

$$Entropy(E) = -\sum_{i=1}^{v} P(e_i)\log P(e_i)$$

Entropy (E)=Entropy(emotion) = Entropy(9,2,14)

$$= \left(-\frac{9}{25}\log(\frac{9}{25}) - \frac{2}{25}\log(\frac{2}{25}) - \frac{14}{25}\log(\frac{14}{25})\right)$$

$= 0.895$

② Conditional entropy of the features LF/HF on the emotion

		Emotion: Pleasure (5,6,7)	Normal (4)	Unpleasure (1,2,3)	Total
Physiological signals	LF/HF	3	2	5	10
	α wave	4	0	4	8
	iemg	2	0	5	7
Total		9	2	14	25

$$CondEntropy(E|T) = \sum_{i=1}^{v} P(t_i) Entropy(E|T = t_i)$$

CondEntropy(E | t_1) =CondEntropy(emotion | LF/HF)

=P(LF/HF)*Entropy(3,2,5)

$$= \frac{10}{25}\left(-\frac{3}{10}\log(\frac{3}{10}) - \frac{2}{10}\log(\frac{2}{10}) - \frac{5}{10}\log(\frac{5}{10})\right)$$

$= 0.412$

③ Information gain of features LF/HF on the emotion

$$Gain(E,T) = Entropy(E) - CondEntropy(E|T)$$

Gain (E,T) = Gain (emotion, LF/HF)

= Entropy(emotion) -CondEntropy(emotion| LF/HF)

=0.895-0.412

=0.483

④ Intrinsic information of LF/HF

		Emotion: Pleasure (5,6,7)	Normal (4)	Unpleasure (1,2,3)	Total
Physiological signals	LF/HF	3	2	5	10
	α wave	4	0	4	8
	iemg	2	0	5	7
Total		9	2	14	25

$$IntI(E,T) = -\sum_{i=1}^{v} \frac{|E_i|}{E}\log\frac{|E_i|}{E}$$

IntI(E, t_1) = IntI(emotion, LF/HF)

$$= -\frac{3}{25}\log(\frac{3}{25}) - \frac{2}{25}\log(\frac{2}{25}) - \frac{5}{25}\log(\frac{5}{25})$$

=0.778

⑤ Gain ratio of features LF/HF on the emotion

$$Gainratio(E|T) = \frac{Gain(E,T)}{IntI(E,T)}$$

GainRatio (E, t_1) =GainRatio (emotion, LF/HF)

$$= \frac{Gain(E, t_1)}{IntI(E, t_1)} = \frac{0.483}{0.778}$$

=0.621

⑥ GainRatio comparison of LF/HF, *α* wave, and iemg

GainRatio (emotion, LF/HF)=0.621

GainRatio (emotion, α wave)=1.148

GainRatio (emotion, iemg) =1.387

	Rank
LF/HF	3
α wave	2
iemg	1

Figure 4.5. The example of using gain ratio applying to this emotion system for feature selection.

4.4.5 Deep Neural Networks

After processing the physiological signal data, we applied the classification methods for emotion recognition. In particular, we used DNN, a digital simulation of the biological deep neural networks [88]. Corresponding to the organism's nervous system, the artificial neural network is also composed of a large number of neurons as basic functional units, as in the many nerve cells of a biological nervous system [89], constituting neural modules with different functions. Each module performs its functions and cooperates to complete varied tasks.

DNN is a supervised learning method, described by hidden layers and a softmax classifier; each layer undergoes a layer-by-layer training initially before the whole neural network is trained. Furthermore, DNN training minimizes the difference between an output and an input. In this paper, we necessarily had to label the corresponding physiological data before learning. The emotional label is the emotional evaluation data for the stimuli tested during the experiment. We specifically used the activation function ReLU (rectified linear unit) and gradient descent algorithm for our proposed DNN for processing of a highly nonlinear problem; moreover, we employed softmax layer for classifying the learned features of the deep network structure. The weight and bias parameters of the softmax layer are trained through the supervised learning methods. After the network has completed learning of the parameters in the softmax classifier, the algorithm must fine-t

-

propagation processes are used to learn network weights and biases based on marked training examples, for minimizing classification errors.

An activation function ReLU (Eq. 4.10) is used as a neuron in this DNN model. Using ReLU can better mine the relevant features and fit the training data. Compared to other activation functions, it shows some advantages: For linear functions, ReLU is more expressive, especially in deep networks; for non-linear functions, ReLU does not have a vanishing gradient problem, which makes the model converge to a stable state [125].

$$ReLU(x) = \begin{cases} x & ,x > 0 \\ 0 & ,x \leq 0 \end{cases} \tag{4.10}$$

In the output layer, this DNN utilizes the softmax to give all predicted value to become probability. Softmax function [127] can make the calculation more easily when conducting the derivative. Thus, it can let model become more efficiency while training. The calculation is expressed in the Eq. 4.11.

$$\sigma_i(z) = \frac{e^{z_i}}{\sum\limits_{j=1}^{c} e^{z_j}}, i = 1, .., c \tag{4.11}$$

where $\sigma_i(z)$ is probability of i class (in our case, i=3). is input variables (in our case, z is physiological features) c is the numbers of class (in our case, m=3)

The loss function (cost function) of this DNN model is using cross-entropy to measure the difference between predicted class (σ_i) and the actual class(σ_{a_i}). Equation 4.12 indicates the formula of cross-entropy [128]. Using cross-entropy can employ easier equation which would not make the training likely to stall out compared with using mean squared error (MSE). When cross entropy small, it means two distribution (predicted class and actual class)more close to each other.

$$L = -\sum_{i=1}^{n} \sigma_{a_i} \log \sigma_i \tag{4.12}$$

where L is loss function. In the L, it comprised of the weighting (m), features (z) and bias (b). σ_{a_i} is probability distribution of the actual class. σ_i is probability distribution of the predicted class (it is also the solution of softmax).

Gradient descent algorithm [126] uses in this DNN to optimize the loss function (L). The gradient descent algorithm is an iterative process. The current value is used to calculate the next value, and this value will be used as the current value of the next calculation process. By this way, iterate continuously to find the best parameter (when the loss function is equal to 0 or very close to 0). The general form of equation of gradient descent algorithm is expressed in Eq. 4.13

$$\psi_{i+1} = \psi_i - \zeta \nabla L(\psi_i) \tag{4.13}$$

where ψ_i is current value and ψ_{i+1} is next value. ζ is learning rate. In this DNN model, ψ includes weighting (m), features (z) and bias (b). The goal of this algorithm is to minimize the loss function. ∇L aims to do the partial derivative of weighting (m) and bias (b). Then, through iterative process, until loss function L equals to 0 or very close to 0, the best parameters of weighting and bias can be obtained. Thus, we can build the DNN.

Herein, by collecting all physiological data and questionnaire answers from 20 subjects, we built the training set to create the DNN models. We constructed two classifiers, one with 9 neuron nodes of valence emotional states and the other with 11 neuron nodes of arousal states (totally 17 parameters (based on high contribution value) were selected for being the input variables). In

t

-fitting will occur; otherwise, under-fitting is expected. The softmax classifier outputs the probability of categorizing the emotional states, where the final discriminant results are the most probable. Figure 4.6b reveals the accuracy and loss function of the valence and arousal classifiers (learning rate: 0.01; number of epoch: 500). Results of the test sets indicate that our constructed DNN was able to fit the training sets and then achieve high accuracy with low loss.

4.4.6 T method of Mahalanobis–Taguchi System

Subsequently, we divided the emotions on both axes into three classes. However, based on the results, we could know only the classes of emotions, but not their intensity; as such, we used the T method of the Mahalanobis–Taguchi system (MTS) for prediction.

The T method technique was developed by Genichi Taguchi for overall estimation of calculated values based on the signal-to-noise (S/N) ratio [90]. Compared with MTS, this method does not need to use either the Mahalanobis distance, or the Gram–Schmidt orthogonalization, to remove variables. In general, the T method follows a three-step procedure.

First, a unit space is chosen from a sample dataset (for an a number of sample datasets), including the output values. Thus, the unit space ($x_{ij}; i = 1, 2, \dots n; j = 1, 2, \dots k$) is the dataset that presents the relation between the input and the output values ($y_{ij}; i = 1, 2, \dots n; j = 1$and 2) [90,91]. The unit space scale is shown in Table 4.3, for n number of sample data. The input and values represented the extracted features and the questionnaire results, respectively.

TABLE 4.3: Unit space scale.

Unit space	Feature items (input value)					Output value	
	x_1	x_2	x_3	$\dots$	x_k	Valence	Arousal
Sample 1	x_{11}	x_{12}	x_{13}	$\dots$	x_{1k}	y_{11}	y_{12}
Sample 2	x_{21}	x_{22}	x_{23}	$\dots$	x_{2k}	y_{21}	y_{22}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\dots$	$\vdots$	$\vdots$	$\vdots$
Sample n	x_{n1}	x_{n2}	x_{n3}	$\dots$	x_{nk}	y_{n1}	y_{n2}
Average value	$\bar{x_1}$	$\bar{x_2}$	$\bar{x_3}$	$\dots$	$\bar{x_k}$	$\bar{y_1}$	$\bar{y_2}$

Second, the signal space is constructed with the rest of the sample data after selection of the unit space. The data of the signal space would be normalized by subtracting its average values

$(X_{ij} = x_{ij} - \bar{x_k}; M_{ij} = y_{ij} - \bar{y_k})$ [90, 91]. Normalization of the signal space (input value: $X_{ij}; i = 1, 2, \ldots l; j = 1, 2, \ldots k$; output value: $M_{ij}; i = 1, 2, \ldots l; j = 1$and 2) measures the data offset from a given unit space. The number of the signal space datasets is $l = a - n$. Table 4.4 illustrates a normalized signal space scale. Furthermore, the unit and signal spaces are used for construction and validation of the predictive model.

TABLE 4.4: Normalization of the signal space scale.

Signalt space	Feature items (input value)					Output value	
	x_1	x_2	x_3	$\ldots$	x_k	Valence	Arousal
Sample 1	X_{11}	X_{12}	X_{13}	$\ldots$	X_{1k}	M_{11}	M_{12}
Sample 2	X_{21}	X_{22}	X_{23}	$\ldots$	X_{2k}	M_{21}	M_{22}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ldots$	$\vdots$	$\vdots$	$\vdots$
Sample l	X_{l1}	X_{l2}	X_{l3}	$\ldots$	X_{lk}	M_{l1}	M_{l2}

Third, sensitivity (β) (the sensitivity of the output concerning the input data) and S/N ratio (η) are calculated using Eqs. (4.14) and (4.15) [90, 91], respectively. These data give an overall estimation of the actual output value. Table 4.5 shows the sensitivity ($\beta_{j(1,2)}$) and S/N ratio ($\eta_{j(1,2)}$) of each x_j.

$$\beta_{j(1,2)} = \frac{\sum_{i=1}^{l} M_{i(1,2)} X_{ij}}{r}, \quad j = 1, 2, ..., k \tag{4.14}$$

$$\eta_{\ (1,2)} = \left\{ \begin{array}{ll} \frac{\frac{1}{r}(S_{\beta j(1,2)} - V_{ej(1,2)})}{V_{ej(1,2)}}, & (S_{\beta j(1,2)} > V_{ej(1,2)}) \\ 0, & (S_{\beta j(1,2)} < V_{ej(1,2)}) \end{array} \right\}, j = 1, 2, ..., k \tag{4.15}$$

From the mentioned steps, the predictive model can be established, and the overall predicted output (Y), which is expressed in Eq. (4.20), can be obtained by a weighted integration with the corresponding S/N ratio.

where parameters r, $S_{\beta j(1,2)}$, $V_{ej(1,2)}$, and S_{Tj} are calculated as follows:

$$r = \sum_{i=1}^{l} M_i^2 \tag{4.16}$$

$$S \qquad \frac{}{r}, j = 1, 2, ..., k \tag{4.17}$$

$$V_{ej(1,2)} = \frac{S_{Tj} S_{\beta j(1,2)}}{r}, j = 1, 2, ..., k \tag{4.18}$$

$$S_{Tj} = \sum_{i=1}^{l} X_{ij}^2, j = 1, 2, ..., k \tag{4.19}$$

$$Y_{i(1,2)} = \frac{\eta_1(1,2) \times \frac{X_{i1}}{\beta_1} + \eta_2(1,2) \times \frac{X_{i2}}{\beta_2} + L + \eta_k(1,2) \times \frac{X_{lk}}{\beta_k}}{\sum_{i=1}^{k} \eta_{j(1,2)}}, i = 1, 2, ..., l \tag{4.20}$$

TABLE 4.5: Sensitivity and S/N ratio of each feature.

	Feature items (input value)								
	x_1		x_2		x_3		...	x_k	
	Valence	Arousal	Valence	Arousal	Valence	Arousal	...	Valence	Arousal
Sensitivity	β_{11}	β_{12}	β_{21}	β_{22}	β_{31}	β_{32}	...	β_{k1}	β_{k1}
S/N ratio	η_{11}	η_{12}	η_{21}	η_{22}	η_{31}	η_{32}	...	η_{k2}	η_{k2}

4.4.7 K-Means

K-Means is a clustering algorithm that divides samples into different categories based on the similarity between samples. For different similarity calculation methods, different clustering results will be obtained. The commonly used similarity calculation method is Euclidean distance method. K-Means is an unsupervised learning algorithm that is mainly used to automatically classify similar samples into one class. Since K-Means algorithm can run on a given complete data set, no training data is needed [129]. 1. We first set how many (*k*) clusters we want to divide into. 2. Decide numbers of center points. In the feature space (a high dimensional space; in our case, data is physiological signals with emotion) to randomly give μ_c group center points. 3. Calculate the Euclidean distance between each data and center points. 4. Classify each data to the nearest cluster of center point. 5. Use classified data to update the new cluster. 6. Repeat 3–5 until the position of center point is not change (convergence).

$$argmin \sum_{g=1}^{k} \sum_{i=1}^{n_c} ||z_i - \mu_c||^2 \tag{4.21}$$

where k is the numbers of clusters (in our case, for one emotion dimensional classifier is 3 clusters). μ_c is centroid of cluster (center point), $||z_i - \mu_c||^2$ is Euclidean distance of physiological signals (z_i) to centroid of cluster. In our case, the data in the feature dimensional space are physiological signals with emotion score.

4.4.8 Naive Bayes

Naive Bayes classifiers are highly scalable, they thus require parameters that have a linear relationship with the variables in the learning problem [139]. It is Supervised learning. Maximum likelihood training can be accomplished by evaluating a closed-form expression, which only takes linear time and does not require the time-consuming iterative approximation used by many other types of classifiers. In this method, the goal is to obtain the probability of finding label. Bayes' theorem (Eq. 4.22) is a theorem about conditional probability of random events I and Z.

$$P(I|Z) = \frac{P(Z|I)P(I)}{P(Z)} \tag{4.22}$$

where $P(I|Z)$ means a conditional probability (posterior probability): the likelihood of event I occurring given that Z is true. $P(Z|I)$ also refers to a conditional probability: the likelihood of event Z occurring given that I is true. $P(I)$ and $P(Z)$ marginal probability of observing I and Z. In our case, the Z refers to physiological features, and the I refers to the emotional class (for one emotion dimensional classifier is 3 classes).

For instance, If we attempt to make a classification of physiological feature z_1 belongs which classes (I_1, I_2 and I_3) t ($P(I|z_1)$), marginal probability ($P(I)$), posterior probabilities ($P(z_1|I)$)... etc. of all subjects physiological feature z_1 which is labelled to which classes (I_1, I_2 and I_3) as shown in Eq. 4.23.

$$P(I|z_1) = \frac{P(z_1|I)P(I)}{P(z_1)} = \frac{P(z_1|I)P(I)}{P(I_1 z_1)P(I_2 z_1)P(I_3 z_1)} \tag{4.23}$$

4.4.9 Support Vector Machine

SVM is a supervised learning method. It uses the principle of statistical risk minimization to estimate a classified hyperplane. The basic concept is very simple. It is to find a decision boundary that allows the boundary between two classes (margins) is maximized so that it can be perfectly distinguished [138]. For instance, doing the classification problem in the 2D condition, at first, arbitrary line equation can be expressed Eq. 4.24

$$i(z) = wz + b \tag{4.24}$$

where, in our case $i(z)$ is the equation for emotion of physiological signals (z). w and b are parameters. Then, calculate the distance $s_{z_0 \rightarrow i(z)}$ from any point z_0 to the line $i(z)$ is expressed

Eq. 4.25

$$s_{z_0 \to i(z)} = \frac{w_0 z + b}{||w||} \tag{4.25}$$

t . 4.26.

$$argmax \frac{1}{||w||} min[i_i(wz_i + b)] \tag{4.26}$$

where z_i and i_i are support vector, which is closest point on the margin. In our case, z_i and i_i can respectively respond to physiological signals and questionnaire score, then through iterating process of using the Eq. 4.26, we can find the hyperplane by obtaining the best parameters of w and b. The obtained equation is the decision boundary. After that, we can use the obtained equation to judge the new input physiological signals are belonged to which class.

4.5 Experiment and Results

4.5.1 Normative–Affective Stimuli

Samson et al. (2015) [101] proposed a film library storing 199 film clips (51 positive, 39 negative, 59 mixed, and 50 neutral), which were selected from 300 clips. These film databases are available for eliciting positive, negative, and mixed emotional states. The emotions of 411 participants stimulated by watching the clips were recorded and analyzed. Based on the participants' ratings, the researchers could give the films an accurate judgment of the emotion they elicit.

4.5.2 Experiment Devices

Figure 4.7 shows the devices of measured for brainwave, EMG (electromyography), and HRV (heat rate variability) acquired using EMOTIV EPOC+, Personal EMG, and myBeat, respectively.

(1) Brainwave: We used EMOTIV EPOC+ [92] with 14 channel electrode caps to collect the brain signals. The 14 channels were AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. We used two references (CMS/DRL) at P3/P4. The sampling rates were configured at 128 Hz. Built-in digital 5th order sinc filter (at 50–60 Hz) was applied to EEG signals at a bandwidth of 0.16–43Hz.

(2) EMG: We used Personal EMG [93] as our surface muscular activity acquisition device. The EMG and iEMG (integrated electromyography) were sampled at 3000 Hz using a 12-bit A/D

converter. EMG sensors were placed on zygomatic and corrugator muscles for measurement of "smile" and "frown," respectively.

(3) HRV: We used myBeat [94] to obtain the heartbeat signals. Sampling rates were 1000 Hz. From a matched visualized software, we were able to obtain real-time records of people's heart rate. We determined LF/HF (LF: low frequency (0.04–0.15 Hz)/ –0.4 Hz)) ratio to understand the balance of a human autonomic nervous activity.

Consideration of the practical application, it is necessary to prepare the simple wearable devices without losing the accuracy of recognition emotion. In this study, we used the portable brainwave detector, wearable heartbeat detector, and muscle activities detector to build the emotion recognition system. Muscle activities detector could be replaced to a wireless type of muscle activities detector in the future. Through consideration of the practical application and the effective physiological signal selection, the authors prepare these three physiological signals.

4.5.3 Experiment Protocol

Before the experiment, the authors carefully explained the experiment condition and attained the consent of each subject. We did not force the subjects to conduct this experiment. Twenty healthy students (16 males and 4 females; 21–27 years old) participated in the emotion elicitation experiments, presented in a rigorous arrangement to ensure the quality of the collected physiological signals. Figure 4.8 depicts the actual experimental scenario. Elicitation materials consist of 30 films selected from the film library. At the experiment onset, the MVC (maximum voluntary contraction) of each participant was measured for preliminary assessment of the ultimate ability of their muscle activity. The setup of the emotion elicitation protocol was as follows:

(1) Rest period: The subjects were asked to calm themselves and relax for 1 min. The generated physiological signals were recorded as their baseline.

(2) Emotion elicitation period: The subjects were asked to watch the emotional stimuli clips.

(3) Self-assessments period: After watching each clip, the subjects were instructed to evaluate their emotion by completing a 30-s survey questionnaire.

(4) Washout period: Before going to the next clip, the subjects watched a 30-s washout video, mainly of a landscape accompanied by light music, to eliminate the emotional influence of the previous clip.

Figure 4.9 describes the entire emotion elicitation process. Compared with pure visual or auditory stimulation, watching a video film can simultaneously stimulate people's visual and auditory senses and, thus, can give them a stronger sense of substitution and better emotional evocation. Throughout the experiments, the subjects were instructed to wear three physiological detectors. In the experiment, the number of subjects exhibited gender imbalance. However, to prevent the difference caused by gender, we had eliminated the individual difference for each subject through processing the physiological baseline signal.

4.5.4 DNN Results

As mentioned earlier, we normalized the experimental data of physiological signals for various emotional states. We selected a total of 460 emotional samples as the training set for the classifier and used another 50 samples as the test set. We can separately divide each valence and arousal state into three groups using our proposed DNN and achieve a classification accuracy of up to 79.2%, for discriminating the valence state (un-pleasure, neural, and pleasure), and 81.1%, for discriminating the arousal states (un-excited, neural, and excited). To validate this accuracy, we employed other algorithms (SVM, Naive Bayes, and K-means) and compared their accuracy with that achieved by DNN. For the comparison, we conducted several classification accuracy measurements and determined the average accuracy, as shown in Fig. 4.10. Results confirmed that our method could attain the highest accuracy following the same data processing procedure. As classification accuracy is sometimes influenced by the initial weight and bias of the data, we moderately adjusted these parameters in each layer of the whole neural networks. The layered structure of the neural network maps the sample in the original space into a new feature space through a layer-by-layer feature transformation, thus making the classification easier. Moreover, by feature selection, it can effectively improve the classification accuracy by extraction of the most important input features to the DNN while eliminating the worse effect from irrelevant features. We can dig a deep relationship between the features through the structure of DNN; therefore, our DNN classifier is capable of recognizing human emotions in the next step.

Through individually discriminating the valence and arousal states into three groups, we were able to obtain a combination of the nine emotional states. Figure 4.11 gives the recognition results of DNN. The graph on the left shows the results of combining the two classifiers on a 2D plane, where the nine emotional states are displayed; each color marker represents the data recognizable in the specific emotion class, such as "excited but un-pleasure." Moreover, the cross symbols represent unrecognized data, which contain misclassified emotions. On the other hand, the graph on the right presents grids that correspond to the emotional states of the left-side graph and their respective classification accuracy. Here, 27/11 would mean that for 38 data, 27 are recognized and 11 are unrecognized, thereby giving an accuracy of 27/38 $\times$ 100% = 71.1%. F - of-view of the database results, we believe that good emotion prediction is achieved when the user is stimulated by a specific film, which is depicted by our recognition results that were located at the region similar with that of the database. Moreover, we think that better emotion prediction is achieved when a specific film stimulates the user, which is depicted by our recognition results and the user response (questionnaire) being located in the same region. Nevertheless, based on our experiences with different people, our recognition method can achieve approximately 70% of accuracy, indicating its feasibility, and further, its ability in general, to predict real emotion.

4.5.5 T Method Results

Following the procedure in Section 4.4.6, we utilized the specified unit and signal spaces to individually predict the output on the two axes (valence and arousal states). Furthermore, based on the two distributions (positive and negative states on a single axis) of the predicted output, we could respectively classify the "unpleasant or pleasant" and "deactivation or activation" on the valence and arousal states.

With this method, selection of the unit space would create substantial influence on the results. At the first trial, we selected the datasets of score 4 as unit space for the two axes; however, the results yielded a figure of the two distributions overlapping. Thus, we could not use this dataset as unit space to classify the emotional state. Next, we applied the datasets of other scores. Finally, for the valence state, we found the datasets of score 7 as unit space giving the best classification results; the overall distribution results displayed that "happy" and"unhappy" can be discernibly classified on the valence state. Figure 4.12a shows the distribution of scores 1-6 against the overall distribution: Scores 1, 2, and 3 are locally distributed in the right side from 0 while scores 5 and 6 in the left side from 0. Hence, for the valence state, this situation illustrated overall distribution results having a one-directional tendency (from negative to positive emotion), which is consistent with the direction of the emotional score axis. Correspondingly, on the arousal state, the datasets of score 2 as unit space yielded better classification results ("un-excited" or "excited") than the others. Figure 4.12b shows the individual distribution of scores 1 and 3-7 against the overall distribution: Scores 4 and 5 are locally distributed in the right side from 0 while scores 1 and 3 in the left side from 0. Although some scores showed irregular phenomena, the overall distribution results had a one-directional tendency.

Furthermore, these results indicate that we can observe the emotional intensity in different states through the individually distributed score. To verify the accuracy of the T method, we examined 30 test samples 10000 times. The resulting classification accuracy was 77% and 47% for the valence and arousal states, respectively. The classification accuracy of arousal states showed the low value. We thought that the score distribution mainly concentrated at score 3, 4, and 5, which may lead to difficult to classify the data by using the T method for judging unexcited and excited. We will add more subjects to participate in the emotion elicitation experiments to further acquire the more valid data, then increase the classification accuracy.

4.5.6 Evaluation of Emotion Recognition System Based on DNN

To evaluate the efficiency of this system, we conducted the same emotion elicitation experiment as in Section 3.4. We asked subjects to watch four specific stimuli videos (on the 2D plane; for "un-pleasure and excited, ""pleasure and excited," "un-pleasure and neutral," and "pleasure and neutral" states) and then compared the output of the system with the actual responses (questionnaire results) of the subjects. Figure 4.14 presents the results. We observed that these recognition results have a tendency similar to the specific stimuli. However, the actual emotions of the subjects are the most important. We further compared the actual emotions of the subjects with recognition results. From the actual response results, for the valence recognition, we found that the recognition results could achieve 83.3% recognition accuracy to actual response (here, for 12 results, 10 results are same as actual responses, thereby giving an accuracy of 10/12 $\times$ 100% = 83.3%). For arousal recognition, the recognition results could achieve 50% recognition accuracy to actual responses (here, for 12 results, 6 results are same as actual responses, thus, an accuracy of 6/12 $\times$ 100% = 50%). We believe that when the participants filled out the questionnaire, the answer of the arousal evaluation was too neutral (subjects usually answered score 3, 4 and 5), which may lead to system misjudgment, thus it leads to low accuracy. In the future, we will focus more on the analysis of neutral answers. We believe that increasing the number of subjects and thus improving the deep learning model will help improve accuracy. Although the recognition accuracy was not very high, we still can prove our system that exhibited a possibility to as the practical application in recognizing human emotion. In the current article, our system is applicable to younger people (21-27 years old) and has not yet extended to other age groups, such as the elderly. Due to the different emotional characteristics of different age group people, in the future, we will not only increase the number of subjects but also invite different age group people to conduct more experiments.

4.6 Discussion

We devoted our time on recognizing states of human emotion through classification algorithms. Two methods demonstrated advantages on this respect. Firstly, through DNN, we were able to accurately classify nine states of emotion on a 2D model. During validation, DNN outperformed the classification accuracy of conventional algorithms. In addition, it reduced the calculation time, which makes it very suitable for real-time emotion recognition. Secondly, al-
t

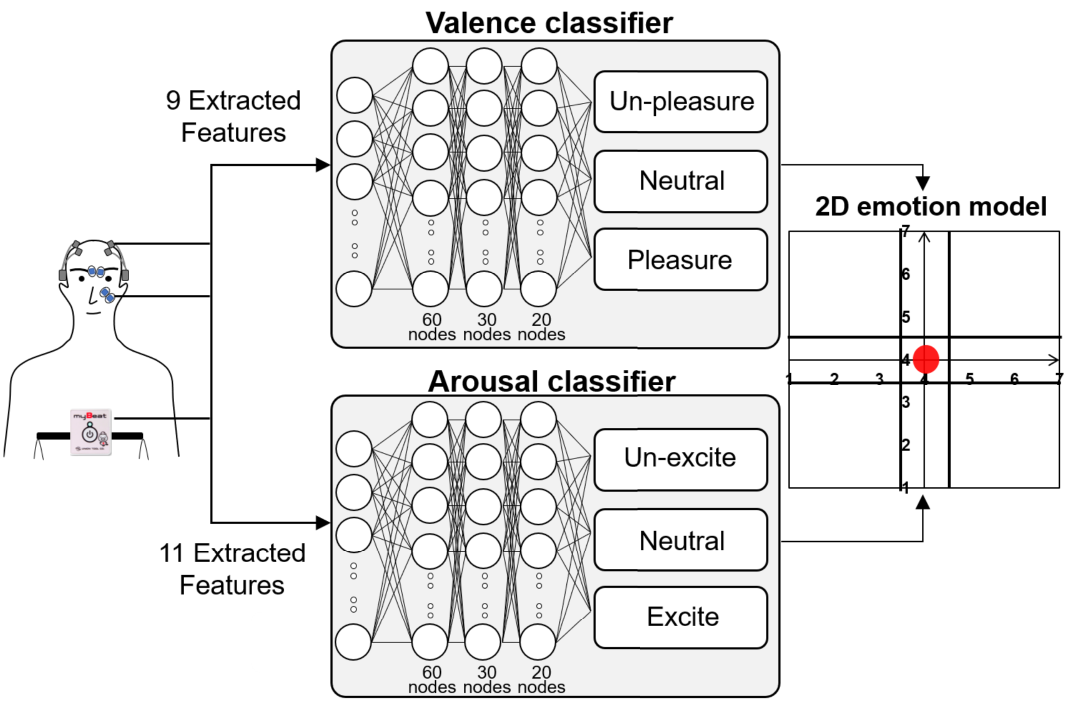
-

dividually distribute the scores of each emotion and determine their intensity. Should assistive robots and other advanced technology be allowed to use the technique we employed in this study, it is inevitable that they could accurately predict or recognize the emotional states and, further, mental states of people.

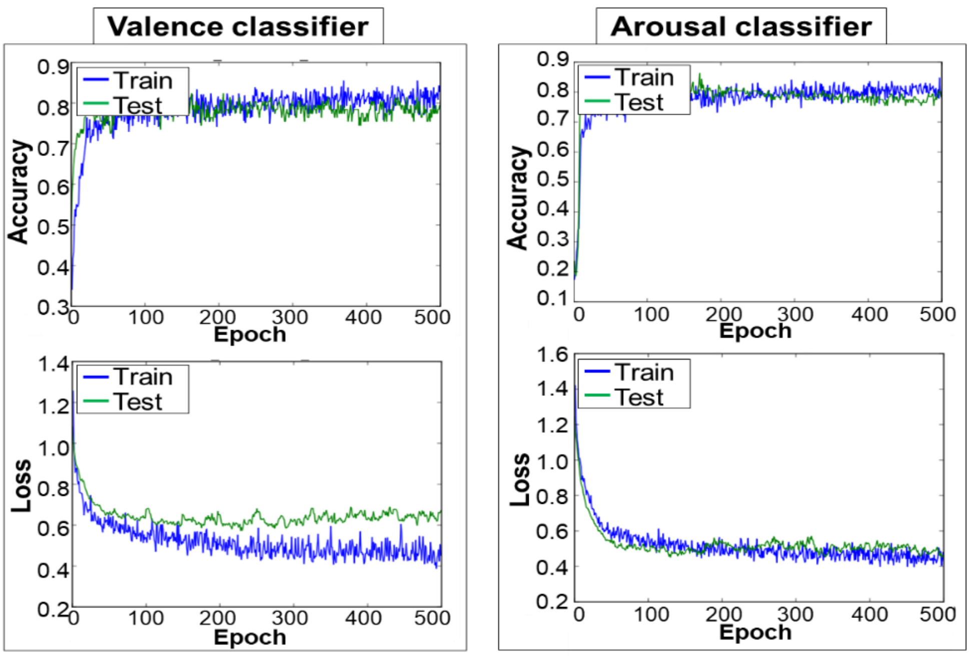
Finally, we developed a real-time emotion recognition system using the proposed DNN as the classifier. The system is presumed to quickly process many physiological signals and accurately recognize emotion. Initially, we collected real-time physiological data from users. Next, the data was analyzed for feature creation, feature selection, and data classification via the Python Software. Before using the platform, we first had to establish the suitable DNN model. A trained DNN model can operate on the physiological signal features input to the emotion recognition platform to output the emotional states we need to identify. Finally, we mapped the classification results on our developed emotion recognition interface. During practical applications, we found that users were uncomfortable wearing the facial sensors, i.e., makeup factor in women. Thus, we tried applying the system without the sensors and observed good results. Figure 4.13 illustrates the respective flow diagram. As a whole, the recognition system is composed of data input/output, feature extraction, DNN, and emotion recognition modules.

4.7 Conclusions

In the research field, emotion recognition has always been met with complicated and comprehensive details. In this study, we proposed algorithms of recognizing human emotions using multiple physiological signal inputs, which may prove beneficial in real-life applications. To study the emotion state of people, a real-time emotion recognition system with the multiple physiological signals (heart rate variability, muscle activities, and brainwave) was proposed. 20 subjects were invited to conduct emotion elicitation test. They had been required to watch 30 specific films while wearing two physiological detectors (brainwave and heartbeat). During the experiment, they had also expressed their subjective emotions via the visualized questionnaire. By collecting 20 subjects' physiological data and questionnaire answers, the training set was built then to create a DNN models as the classifier being an emotion recognition system, which can recognize the nine states of human emotion. A total of 460 emotional samples were selected as the training set for the classifier and used another 50 samples as the test set. Separately each valence and arousal state can be divided into three groups using our proposed DNN and achieve a classification accuracy of up to 79%(test set/training set), for discriminating the valence state (un-pleasure, neural, and pleasure), and 81%(test set/training set), for discriminating the arousal states (un-excited, neural, and excited). The system was validated its superior accuracy over conventional algorithms through a comparison of their respective classification results, such as SVM, Naïve Bayes, and K-means. To extend the application, the sensors of muscle activity was removed because users were uncomfortable wearing the facial sensors, i.e., makeup factor in women. To evaluate the efficiency of this system, the results verified the feasibility in the real emotion prediction (the accuracy of 71 % [system/ questionnaire (quest.)]).



(a) DNN structure of the valence classifiers (9 input features) and arousal classifiers (11 input features). Total 5 layers with 3 hidden layers (1st layer: 60 nodes; 2nd layer: 30 nodes; 3rd layer: 20 nodes)



(b) the accuracy and loss function of the valence and arousal classifiers.

Figure 4.6. Structure of the 2D classifiers, with their accuracy and loss function. (a) DNN structure of valence and arousal classifiers (b) the accuracy and loss function of the valence and arousal classifiers.

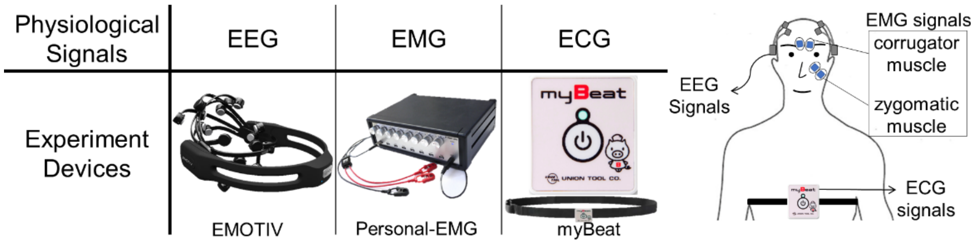


Figure 4.7. Three devices, EMOTIV, Personal EMG, and myBeat, used in the elicitation experiments.

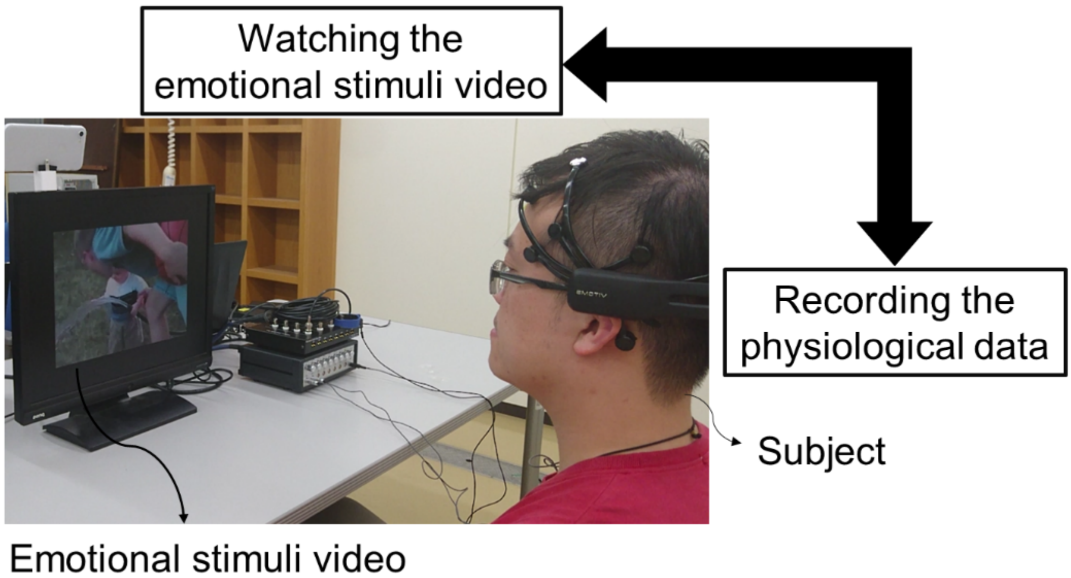


Figure 4.8. Actual scenario of the emotion elicitation experiment.

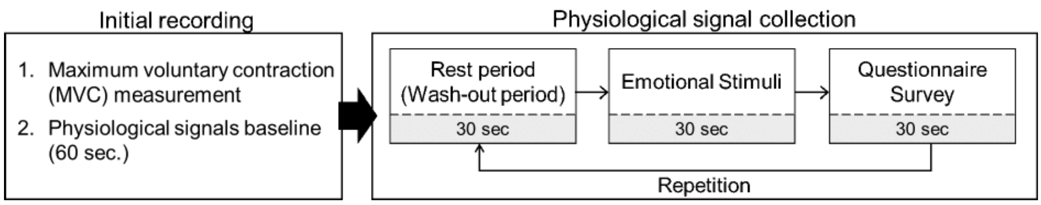


Figure 4.9. Stages of the emotion elicitation experiment process.

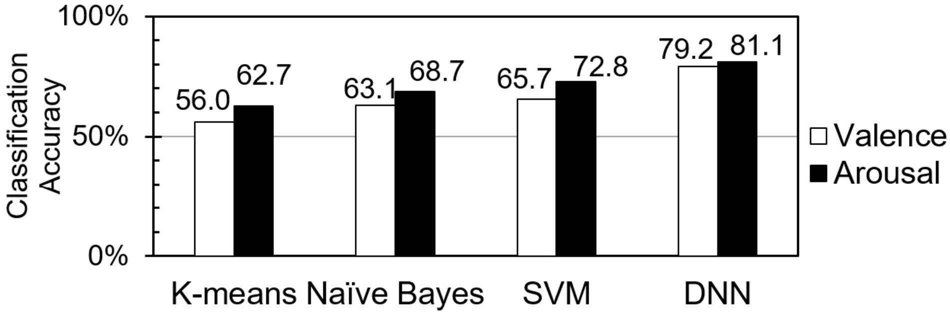


Figure 4.10. Classification accuracy of DNN against selected algorithms accuracy.

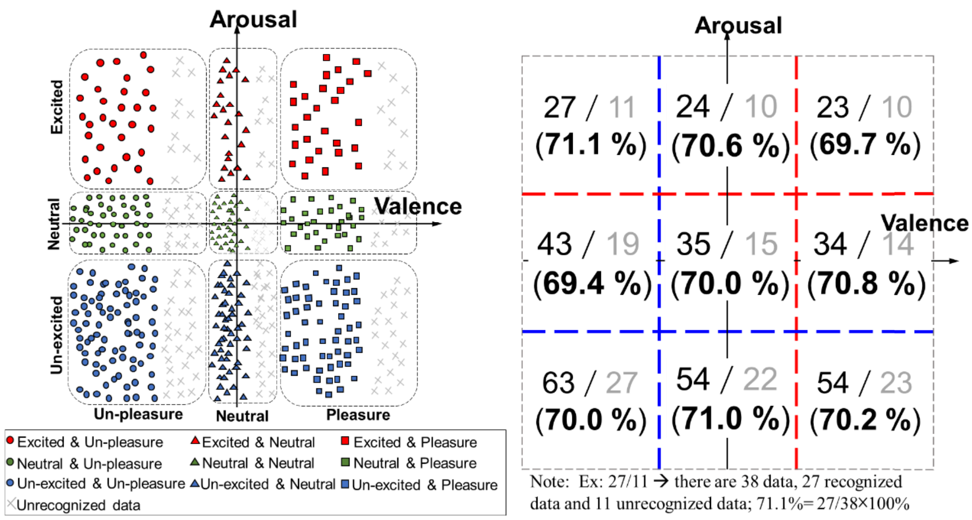
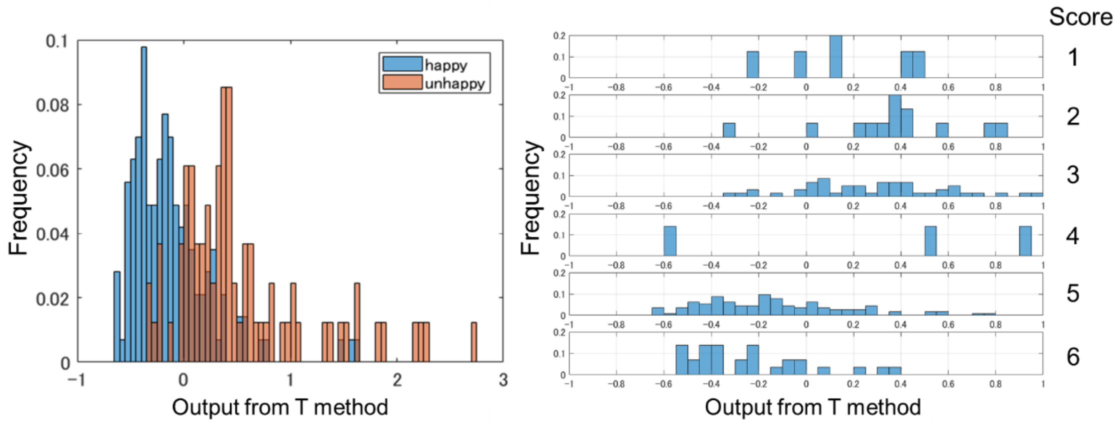
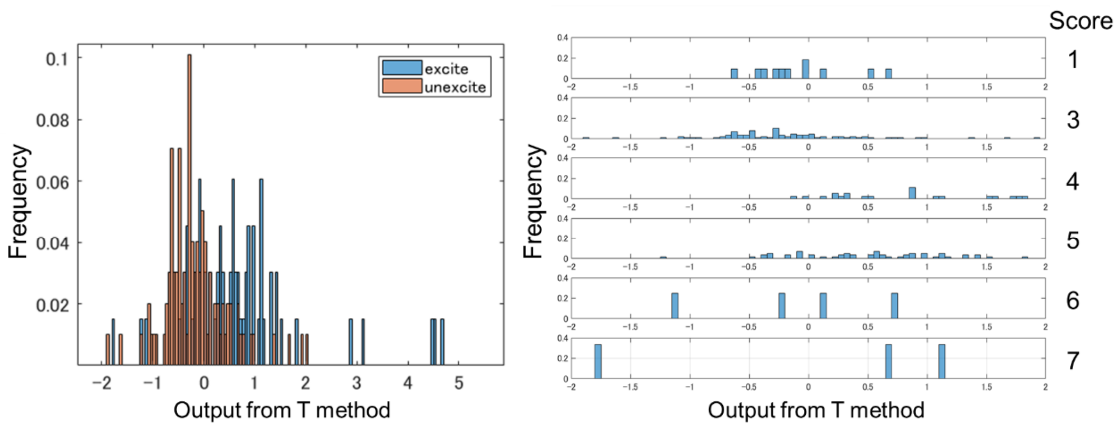


Figure 4.11. Recognition of nine emotional states with classification accuracy.



(a) Valence state distribution with score 7 as unit space.



(b) Arousal state distribution with score 2 as unit space.

Figure 4.12. Results of the T method evaluation. (a) Valence state distribution with score 7 as unit space and (b) arousal state distribution with score 2 as unit space.

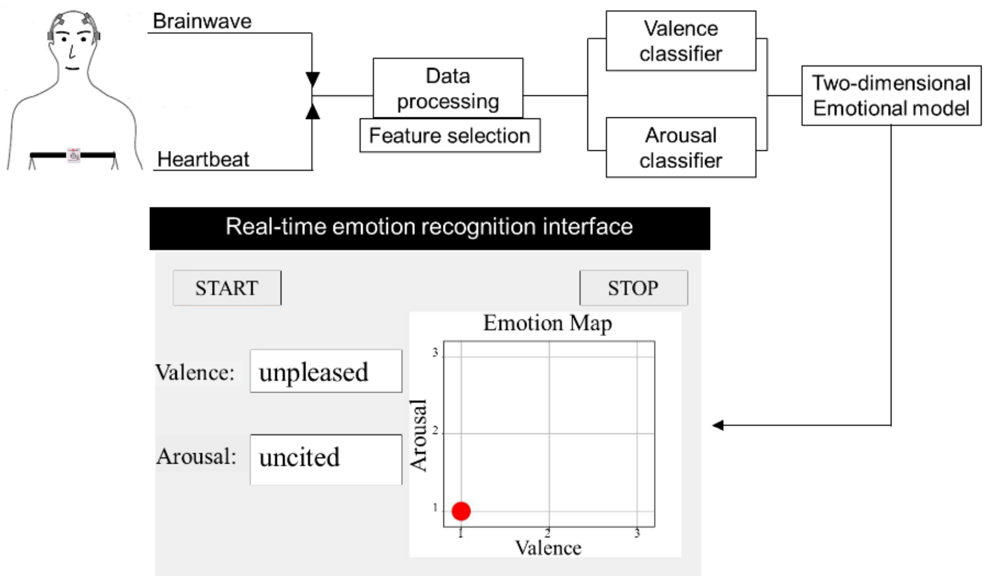


Figure 4.13. Flow diagram of the real-time emotion recognition system.

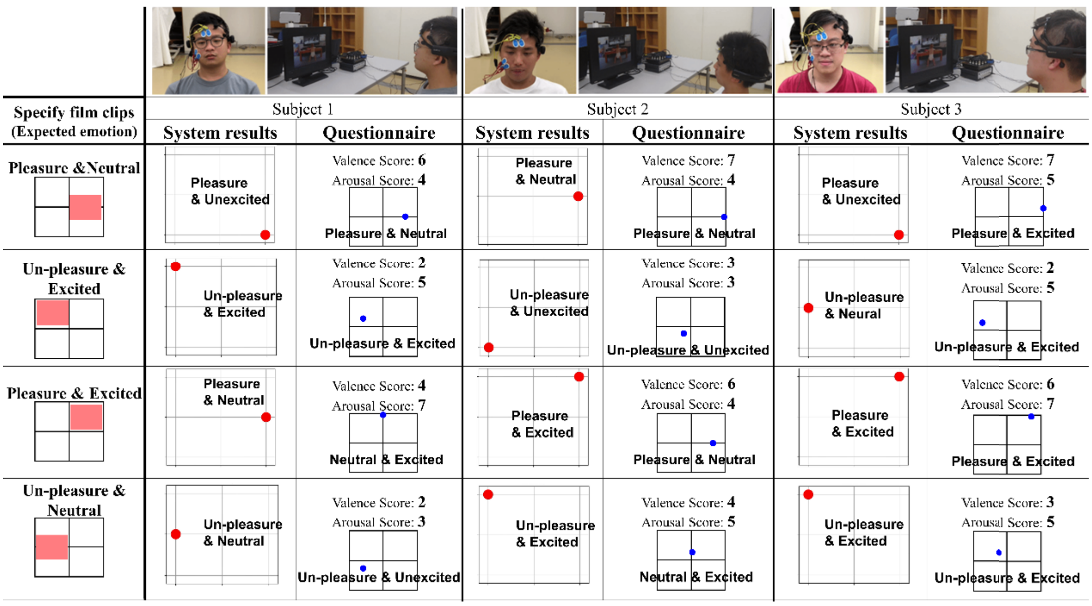


Figure 4.14. Evaluation of the real-time emotion recognition system.

Chapter 5

Applying the Interaction of Walking-Emotion to an Assistive Device for Rehabilitation and Exercise*

5.1 Abstract

This chapter aims to study walking assistance considering emotion evaluation, which can provide the elderly to synchronously gain dual assistance for the promotion of exercise. To achieve the purpose, a hybrid system integrating an emotion system and a compact walking device was proposed. Firstly, we explored the relationship between human emotion and walking conditions. We prepared the walking-emotion relationship experiment further used the two-dimension (2D) emotion map and 2D walking condition map to determine its tendency and relationship. The emotion was elicited by changing the walking condition of people in this experiment. By changing walking conditions, we finally obtained the corresponding results of emotion change; thus, the walking-emotion relationship is achieved. After that, a hybrid assistive system integrating emotion and walking was constructed. To effectively elevate the effect of assistance and maintain motivation, it is necessary to make the users locate at the positive emotional state. Thus, the walking strategies (repeated and cycled walking) were proposed for the promotion of emotion. By questionnaire survey, the results with statistical evaluation proved these strategies with a system can promote the positive emotion of users. By using this system, the elderly can satisfy their mood and with a physical device to reach the goal of exercise. They can thus gain a high sense of achievement further keep motivation and promote confidence in real life without other people help.

*This chapter's contents relate to the published conference paper: Zhuang, J.R. et. al, "Applying the Interaction of Walking-Emotion to an Assistive Device for Rehabilitation and Exercise," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2019), Macau, China, November 3-8, (2019), pp.6489-6494.Indicated in research achievement of international conference [2]; reference:[136]

5.2 Introduction

With the impact of an aging society, the issue of rehabilitation and exercise in the elderly are gradually being concerned in recent years. Aging leads to a decrease in physical activity, which further causes the elderly bedridden, then leading to stroke. For prevention of stroke, proper exercise and rehabilitation are good ways for the elderly. Therefore, many assistive devices have been proposed for restoring their body condition. However, from the viewpoint of users, when they start to use the assistive device, they must learn and adapt the assistive device. It is a long-term period. Also, it involves much negative feelings. Due to this reason, most of the users may reduce their willingness to utilize the assistive device, which will result in failure to recover the ability of the body and they will start to refuse to go out. Dunn et al. (2005) [95] mentioned that the positive psychology has an excellent effect for rehabilitation. Accordingly, to keep motivation while undergoing rehabilitation or exercise, the mental condition must be significantly concerned. Hence, not only considers the physical assistance but also it is vital to understand the human mental situation while using an assistive device. To complete the two-way assistance, it is necessary to understand the relationship between physical and mental condition. Walking is one of the most important physical therapy for people who have the issue of walking disorder. Also, walking is a great exercise for the elderly to prevent stroke. However, regardless of the elderly or patients, it is very hard to continue the long-time walking. In this study, we thus proposed to identify the emotion of people during rehabilitation. Many investigations have studied on recognition of emotion from body motions [96, 97]. For walking, psychology proved that the emotion is able to be expressed in gait patterns. Karg et al. (2010) [98] offered a means for analyzing the gait to reveal peoples' emotion. Janssen et al. (2008) [99] employed the kinetic and kinematic data of gait with artificial neural nets to further recognize the emotion. However, the results showed in these studies are inappropriate to apply to the patients in rehabilitation. Generally, the patients' gait and posture are different to healthy people, thus, in this paper, we considered using the direct factors of walking to reveal the emotion-walking relationship.

For physical assistance, many assistive walking devices have been developed to regain disorder issue in walking. For instance, Takaiwa et al. (2009) [32] proposed a walking support shoes via mobile pneumatic technique to generate the power achieving the dorsiflexion assistance. Curara [100] has been designed to improve the walking performance for the elderly and patient. In chapter 3, we designed a new assistive walking device for neuro- rehabilitation and the promotion of exercise. Using the assistance of only the ankle joint, this device triggered a stretch reflex of the user by a small motor. The leg could thus be raised. This device is good for tibialis anterior muscle weakness people who lack the power to conduct the dorsiflexion motion during walking. Users can attain physical assistance by using these assistive devices.

With the development of technology, the robot has extended roles for assisting people to improve the life. Therefore, Human-Robotic Interaction (HRI) technique has been becoming the popular topic in the academic circles. To link human and robot, several papers have devoted to studying their relation further attempting to control the robot by the human mind. During the medical engineering filed, it is necessary to develop the HRI technique to link people and assistive device. From the viewpoint of users, they especially expected the assistive device could comply with their mind to achieve their requirement. At the beginning period while using the assistive device, users are unfamiliar with it, they must to learn and adapt it. Thus, users are very easy to give up or decrease their willingness to do rehabilitation while using the assistive device at the beginning period. These problems may cause users failures to regain body health, and then induce bedridden. Thus, from these reasons, we have to understand to know the mental condition of users and to keep their motivation during rehabilitation. In Maslow's hierarchy of needs theory, the lower-level needs of the hierarchy must be met before individuals can meet the higher-level needs. Consideration of psychological state in people who undergoing rehabilitation or exercise period, the feeling of self-actualization is very important. In order to accomplish the goal of rehabilitation or exercise, from the perspective of physical support (external), powerful devices can help users achieve their goals quickly; however, the user's mental state (internal) does not have a self-actualization feeling. If the user can satisfy his or her own mood (staying positive emotion) and then combine the physical device to achieve the goal, the user will have a sense of accomplishment, as shown in Fig. 5.1. Thus, they can maintain the motivation for rehabilitation or exercise. It is necessary to develop a hybrid assistance system which integrates mental and physical aspect for improving the users' experience. To reach the aim of maintaining the motivation and long-term exercise, there is one assistive device which have considered mental and physical aspect of the user. Lokomat [120] is a assitive device which can assist the three joints (hip, keen, and hip.) of the people for rehabilitation, as shown in Fig. 2.3. Meanwhile, Lokomat have proposed to make user longer walking by preparing the camera. However, this device could not understand the emotion of people. It is difficult to define the users' motivation is maintained.

5.3 Purpose

The final goal of this study aims to study walking assistance considering emotion evaluation, which can provide the elderly to synchronously gain dual assistance of promotion of emotion and walking during the exercise. Therefore, elderly can thus maintain the motivation to further long-term exercise. From the literature review, the existed device could not determine the people's mental state because it did not measure the users' emotions. In addition, how to promote the user mental condition is a vital issue. However, the existed device's method was not verified. Thus, it is hard to realize to keep the motivation. To the final goal, a new assistive hybrid system should be developed by considering emotion evaluation while walking assistance. Additionally, to promote and maintain the emotion is necessary to be deeply studied. This chapter aims to realize a hybrid system, which considers four topics as follows: (1)Understand the relationship between walking and emotion (2)Propose the strategy for promotion of emotion (3) Construct a system integrating emotion and walking (4) Propose control strategy for maintaining and promotion emotion to the positive area. Hence, by using this system, the elderly can satisfy their mood and with a physical device to reach the goal of exercise (Fig. 5.1). They can thus gain a high sense of achievement further keep motivation and promote confidence in real life without other people's help.

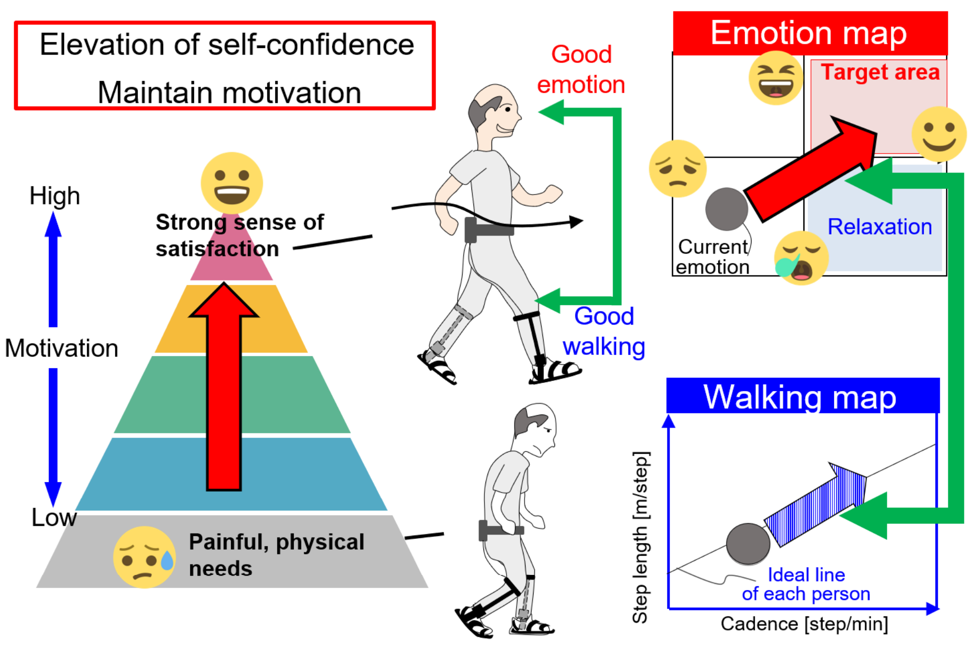


Figure 5.1. Maintain positive emotion with physical assistance for achieving strong sense of satisfaction.

5.4 Related Work

Two-dimension (2D) emotion map [81] and the 2D walking condition map [76] (Fig. 5.2) were utilized to explore the relationship between walking and emotion. In the 2D emotion map, two indicators of valence and arousal are used to measure the emotional state. The valence axis divides the emotion into positive emotions and negative emotions. Positive emotions refer to emotions that make people feel happy and positive. Negative emotions refer to emotions that make people feel sad and negative. The arousal axis reflects the feelings of the activation or deactivation. 2D walking condition map uses two indicators, the cadence [steps/min] and step length [m/step]. Sekiya et al. [76] had experimented the preferred walking ratio (walking ratio [m/steps/min] = step length [step/min]/ cadence [m/steps]) is about 0.006, which was tested by 22 able-bodied people. Additionally, the walking speed [m/min] can be calculated via step length and cadence. The formula is expressed by "$V = S \times C$", here the S, V and C respectively denote the step length [m/step], walking speed [m/min], and cadence [step/min]. The definition of step length and stride length is shown in Fig. 5.3.

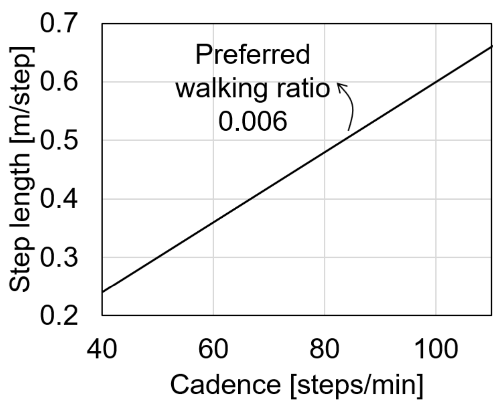


Figure 5.2. 2D walking condition map [76].

This study used the visualized self-assessment manikin (SAM) [82] as the questionnaire for the subjects to respond to their emotion. In traditional emotional evaluation, the lack of understanding of words has often led to the wrong description of emotions. Thus, the non-verbal pictorial assessment is a better means for the subjects easily to describe their feelings. SAM represents a range of pleasure dimensions ranging from smiling to a frown. The range of arousal changes from excited to relaxed. The subjects can select different numerical scales to reflect the intensity of emotion. In this study, we use a 7-point score standard. Both axes increase

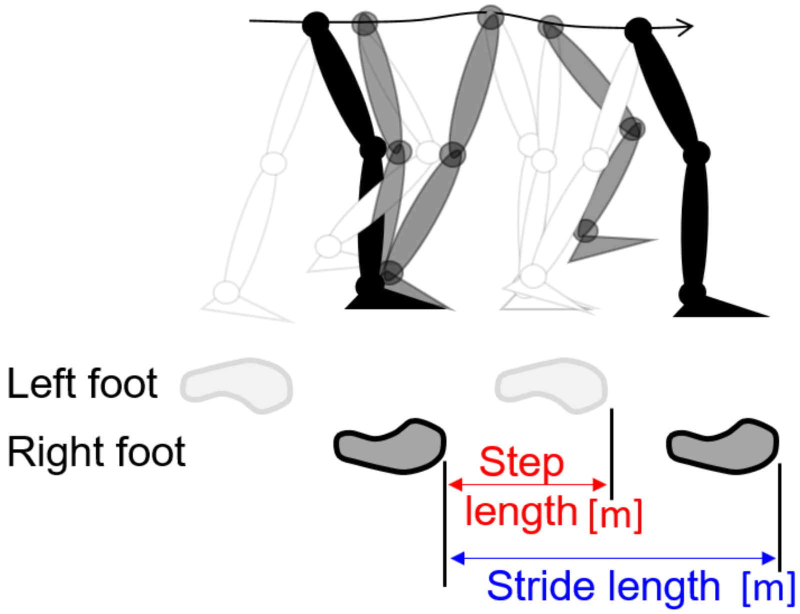


Figure 5.3. During a complete walking cycle, the step length and stride length can be defined.

progressively from level 1 to level 7. Point 4 represents the neutral emotion. Point 7 means the highest arousal and highest pleasure, respectively; Point 1 means the lowest arousal and the lowest pleasure, respectively.

5.5 Evaluation of Emotion-Walking Relationship

Walking condition map and emotion map (questionnaire responses) were employed to explore the relationship. By observing the walking vector (normal walking to specified walking) corresponding to the emotion vector (normal walking to specified walking), the relationship could be determined. Also, the developed emotion recognition system was used to compare with the questionnaire results further show its applicability, as shown in Fig. 5.4. In the analysis of the recognition system (chapter 3), we calculated the features of brainwave and heartbeat which inputted to the deep neural network model further recognized the emotion of people. Fast Fourier Transform was employed to transform the data of time domain into frequency domain. During the experiment, we could get the physiological signals for 30 secs. In the data processing, we removed the beginning sequence data (5 secs) and the final sequence data (5 secs) of the total signals. This procedure was used to filter the fluctuated signals during that period. Thus, in each walking condition, we could get regular physiological signals for 20 secs in each subject.

To eliminate individual differences, all obtained physiological signals were be divided by basic physiological signals which got from normal walking.

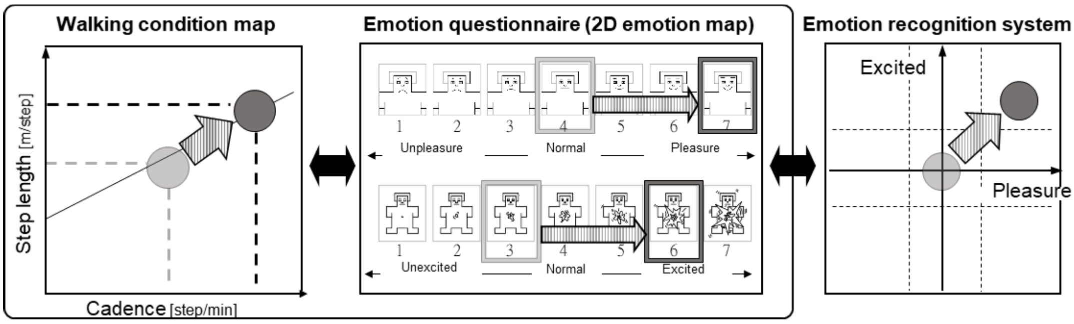


Figure 5.4. Through the walking changes to observe the emotion changes; at the same time, the emotion recognition system is applied to be checked its applicability.

5.6 Emotion-Walking Control System

5.6.1 The Relationship between the Ankle Angle and Step Length

According to the emotion-walking relationship, when people emotion changes, the corresponding walking condition, new target step length (S_T) and new target cadence (C_T), would be indicated on the walking map. The ankle angle and step length existed the linear relationship (Watanabe et al., 2011[105]). To attain its relationship, we conducted the experiment which is to find this relationship. We required three subjects to walk in different conditions (fast, normal, and slow speed) for 20 secs; then, the gait data of ankle dorsiflexion and step length was collected further exploring their relationship. In each walking condition, we respectively picked up 50 completed walking cycles which further collected the corresponding data of angle and step length (total 150 data). Figure 5.5 shows the one of results of this experiment. It shows the walking trajectory and step length existed the relationship while different walking speed. Figure 5.6 exhibited this experiment preparation [133][135].

The experiment results are indicated the variation angle in each specific walking phase. From our proposed walking device (In chapter 3), it assigned the predefined walking target angle and target walking phase. From these predefined values, we could effectively assist walking gait. Thus, according to the experimental results, we defined the ankle angle variation in the five specified walking phases (0-10%, 10-40%, 40-60%, 60-85%, and 85-100%.). p_T denotes the current walking phase. The linear equation of each ankle variation angle and step length in

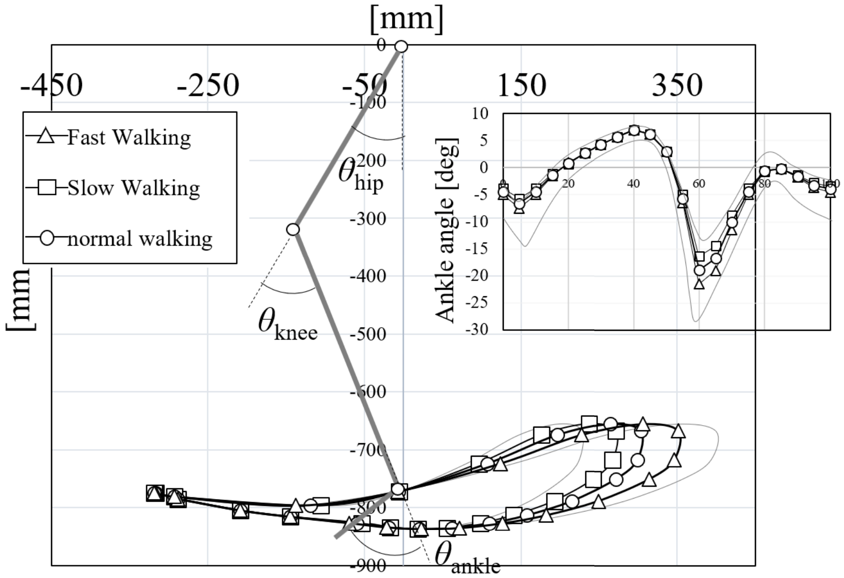


Figure 5.5. Step length and ankle angle variation relationship while different speed.

each phase is indicated in Eq. 5.1. Figure 5.7 exhibited that the relationship of the ankle angle variation and step length in five phases. By emotion-walking relationship, the new target angle variation (θ_{var_T}) [deg] of each specified phase could be obtained by inputting the new target step length (S_T) [m/step] to the Eq. 5.1.

$$\theta_{var_T} = A \times S_T + B = \begin{cases} A_1 \times S_T + B_1 & ,0 \leq p_T < 10\% \\ A_2 \times S_T + B_2 & ,10\% \leq p_T < 40\% \\ A_3 \times S_T + B_3 & ,40\% \leq p_T < 60\% \\ A_4 \times S_T + B_4 & ,60\% \leq p_T < 85\% \\ A_5 \times S_T + B_5 & ,85\% \leq p_T \leq 100\% \end{cases} \tag{5.1}$$

Through curved fitting the experimental results, the parameter A_1 is 7.921, B_1 is -11.47, A_2 is -57.162, B_2 is 65.278, A_3 is -111.16, B_3 is 37.615, A_4 is 73.772, B_4 is -28.328, A_5 is 79.753, and B_5 is -60.644.

5.6.2 The Relationship Between the Cadence and Walking Cycle

Cadence-walking cycle relationship existed the reciprocal relation. Walking cycle (W_T)[sec] is the reciprocal of cadence (C_T)[steps/min]. From the unit, we could understand the walking cycle means: the walking time per one stride [sec/stride]; cadence means: how many steps per one minute [steps/min]. By walking steps or stride (2 steps) to the time, we observed its reciprocal relation. Thus, from cadence (C_T)[steps/min] to walking cycle (W_T)[sec] is expressed in Eq. 5.2.

$$C_T = \frac{steps}{min} = \frac{2 \times steps}{2 \times 60sec} = \frac{stride}{120 \times sec} \tag{5.2}$$

t)[sec] is the reciprocal of cadence (C_T)[steps/min], as expressed in Eq.5.3.

$$\frac{C_T}{120} = \frac{1}{W_T} \tag{5.3}$$

finally, simplify the Eq.5.3. The relationship formula is expressed in Eq.5.4.

$$C_T = \frac{120}{W_T} \tag{5.4}$$

5.6.3 Actuation Procedure of the Emotion-Walking System

The actuation procedure of the emotion-walking system is shown in Fig. 5.9. When the subject's emotion is identified by recognition system, the emotion-walking coefficient α_d and β_d are used as tuning parameters to further calculate the new targeted walking cycle and new target ankle angle.

$$W_{T_{new}} = \beta_d W_T \tag{5.5}$$

$$\theta_{T_{new}} = \alpha_d \theta_T \tag{5.6}$$

where W_T [sec] and θ_T [deg] represent the targeted walking cycle and targeted ankle angle, respectively. α_d and β_d are tuning parameters of emotion-walking feedback. According to the emotion-walking relationship, when people emotion changes, the corresponding walking condition, new target step length (S_T) [m/step] and new target cadence(C_T) [steps/min], would be indicated on the walking map. The concept of tuning parameter α_d is from Fig. 5.5. By understanding the step length of the subjects, the ankle angle variation can be obtained owing to their linear relationship. The calculation process shows in the Fig. 5.8 At the first, the users emotion would be recognized then corresponding to the target walking condition. The new step length and new cadence thus obtain for updating the walking mode of the assistive device. From the new step length (S_T) [m/step] inputting the equations (Eq. 5.1), we can obtain the new ankle angle variation (θ_{var_T}) [deg]. We also had the initial angle variation (θ_{var_N})[deg]. The idea of tuning parameter α_d could be calculated by the ratio of new target angle variation (θ_{var_T}) [deg] and initial target angle variation (θ_{var_N}) [deg]. The calculation is using the θ_{var_T} [deg] divided by θ_{var_N} [deg]. The ratio for individual phase can be gotten. The equation is indicated in Eq. 5.7

$$\alpha_d = \frac{\theta_{var_T}}{\theta_{var_N}} = \begin{cases} \dfrac{\theta_{T_{10\%}} - \theta_{T_{0\%}}}{\theta_{N_{10\%}} - \theta_{N_{0\%}}} & , 0 \leq p_T < 10\% \\ \dfrac{\theta_{T_{40\%}} - \theta_{T_{10\%}}}{\theta_{N_{40\%}} - \theta_{N_{10\%}}} & , 10\% \leq p_T < 40\% \\ \dfrac{\theta_{T_{60\%}} - \theta_{T_{40\%}}}{\theta_{N_{60\%}} - \theta_{N_{40\%}}} & , 40\% \leq p_T < 60\% \\ \dfrac{\theta_{T_{85\%}} - \theta_{T_{60\%}}}{\theta_{N_{85\%}} - \theta_{N_{60\%}}} & , 60\% \leq p_T < 85\% \\ \dfrac{\theta_{T_{100\%}} - \theta_{T_{85\%}}}{\theta_{N_{100\%}} - \theta_{N_{85\%}}} & , 85\% \leq p_T \leq 100\% \end{cases} \tag{5.7}$$

Furthermore, due to the relationship between walking cycle(W_T) [sec] and cadence (C_T) [steps/min], walking cycle is the reciprocal of cadence. From the emotion-walking relationship, the corresponding cadence could be obtained. Thus, β_d is defined by using target cadence(C_T) [steps/min] divided initial cadence(C_N) [steps/min]. The calculation of α_d and β_d as shown in Eq. 5.8.

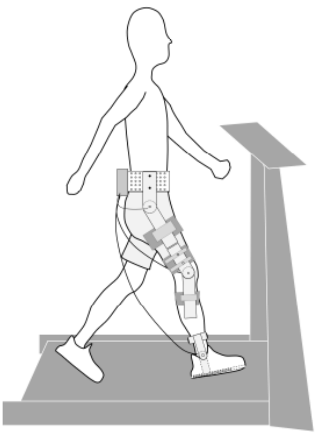
$$\beta_d = \frac{C_T}{C_N} \tag{5.8}$$

The new angular velocity ($\dot{\theta}_{T_{new}}$) [deg/s^2] can thus be recalculated by Eq. 3.1 then to control the motor. The modified equation indicated in the Eq. 5.9.

$$\dot{\theta}_{T_{new}} = \frac{\alpha_d(\theta_{T_{next}} - \theta_{T_{current}})}{\beta_d(p_{T_{next}} - p_{T_{current}}) \times W_T} \times 100\% \tag{5.9}$$

For the control strategy, the obtained emotion (emotion map) would be corresponding to the required walking condition (S_T [m/step] and C_T [steps/min]) (walking map), which would be inputted to the device to update the new target values ($W_{T_{new}}$ [sec] and $\theta_{T_{new}}$ [deg]). Through these formula, we could implement the emotion-walking relationship to further control the assistive device. The users can thus walk effectively not only physical assistance but also the emotion evaluation is considered.

This system is divided into two parts, and one is the assistive device, another is the emotion-walking recognition device. Through the emotion-walking relationship, the user's target walking condition can be obtained as the feedback tuning parameters (α_d and β_d) to update the device's setting parameter. The sampling time of an emotion recognition system is 5 seconds (1-second outputs 4 results, then obtains 20 results within 5 seconds, and selects the results that appear most often as the final output). The sampling time of an assistive walking device is the walking cycle time of the users (default is 1.08 sec). Mainly, the sampling time of this system is dominated by a walking assistive device. To keep the same motion, the assistive walking device should wait for the results of the emotional condition; therefore, the tuning parameter will not be offered the value (α_d=0) from emotion recognition at the slight time. Whereby, the device will gain the zero value of angular velocity; meanwhile, the torque limiter design could make the user continue to walk without breakage of the motor gear. Until current emotion shows up, the device can be tuned to the target motion for walking assistance again. Through using this system, the users can use the emotion to control the walking, and also can use walking conditions to affect the emotion. The users can hence achieve the dual promotion of emotion and walking.



Ankle angle-Step length relationship experiment	
Subjects	3
Conditions	Free walking for 20 second
	1. Fast speed 2. Normal speed 3. Slow speed
Measured data	1. Ankle variation angle (θ_{var}) [deg] 2. Step length (S) [m]

	Picked up		Collected	Total **150** data
Fast walking	⟹	50 walking cycles	⟹	50 θ_{fast} & 50 S_{fast}
Normal walking	⟹	50 walking cycles	⟹	50 θ_{normal} & 50 S_{normal}
Slow walking	⟹	50 walking cycles	⟹	50 θ_{slow} & 50 S_{slow}

Figure 5.6. The experiment of Ankle angle-step length relationship.

5.6.4 The Proposed Methods for Emotion Promotion

The mean idea of developing this emotion-walking assistive system is to more effectively elevate the assistance effect and maintain the motivation to complete the long-term exercise. In Maslow's hierarchy of needs theory, the lower-level needs of the hierarchy must be met before

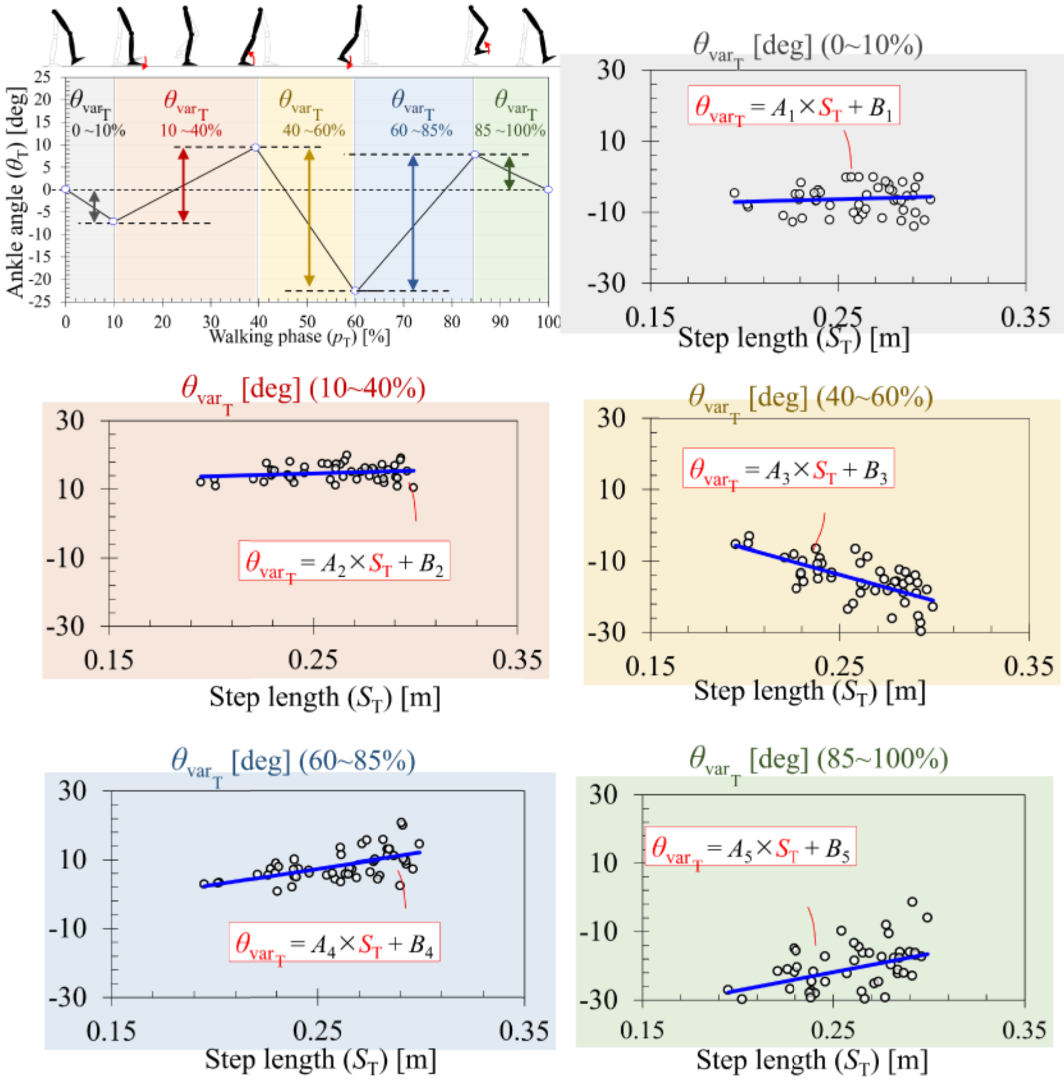


Figure 5.7. Relationship between ankle angle variation-step length in five phases.

individuals can meet the higher-level needs. Consideration of psychological state in people who undergoing rehabilitation or exercise period, the feeling of self-actualization is very important. In order to accomplish the goal of rehabilitation or exercise, from the perspective of physical support (external), powerful devices can help users achieve their goals quickly; however, the user's mental state (internal) does not have a self-actualization feeling. If the user can satisfy his or her own mood (staying positive emotion) and then combine the physical device to achieve the goal, the user will have a sense of accomplishment, as shown in Fig. 5.1. Thus, they can maintain motivation for rehabilitation or exercise. It is necessary to concern on how to maintain and promote positive emotion in the exercise. We proposed the methods by walking strategy to

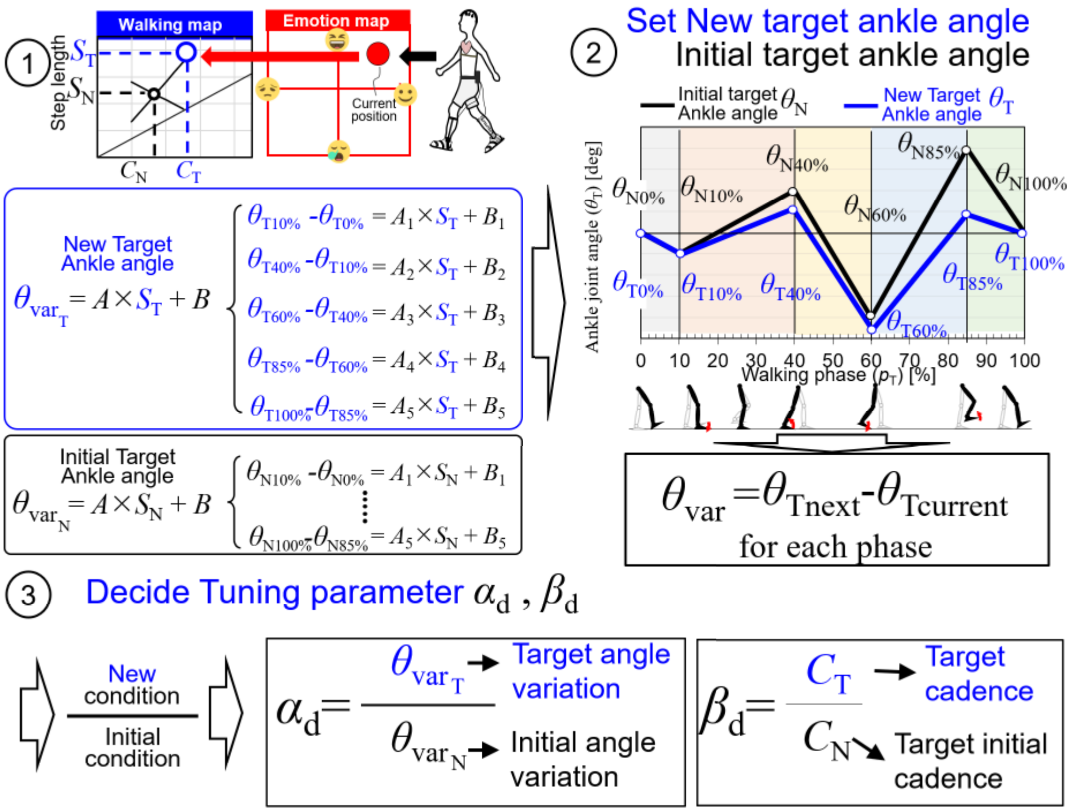


Figure 5.8. Calculation procedure of tuning parameters α_d and β_d.

promote the emotion, as shown in Fig. 5.10. It is necessary to make the people's mental state be located at positive emotions (such as happy, excited, and relaxed) for a long time. The final application of this system is to use in the real situation. The methods of emotion promotion should not utilize extra apparatus to increase the unnecessary burden on the users. The emotion-walking relationship undoubtedly proved their interaction effect. Using walking as the strategy is thus proposed being methods to promotion the emotion for users.

After that, the author concerned on how to maintain and promote the positive emotion by walking condition influence, as shown in Fig 5.10. It is necessary to make the people's mental state be located at positive emotions (such as happy, excited, and relaxed) for a long time.

The final application of this system is to use in the real situation. The methods of emotion promotion should not utilize extra apparatus to increase the unnecessary burden on the users. The emotion-walking relationship undoubtedly proved their interaction effect. Using walking as the strategy is thus proposed being methods to promotion the emotion for users.

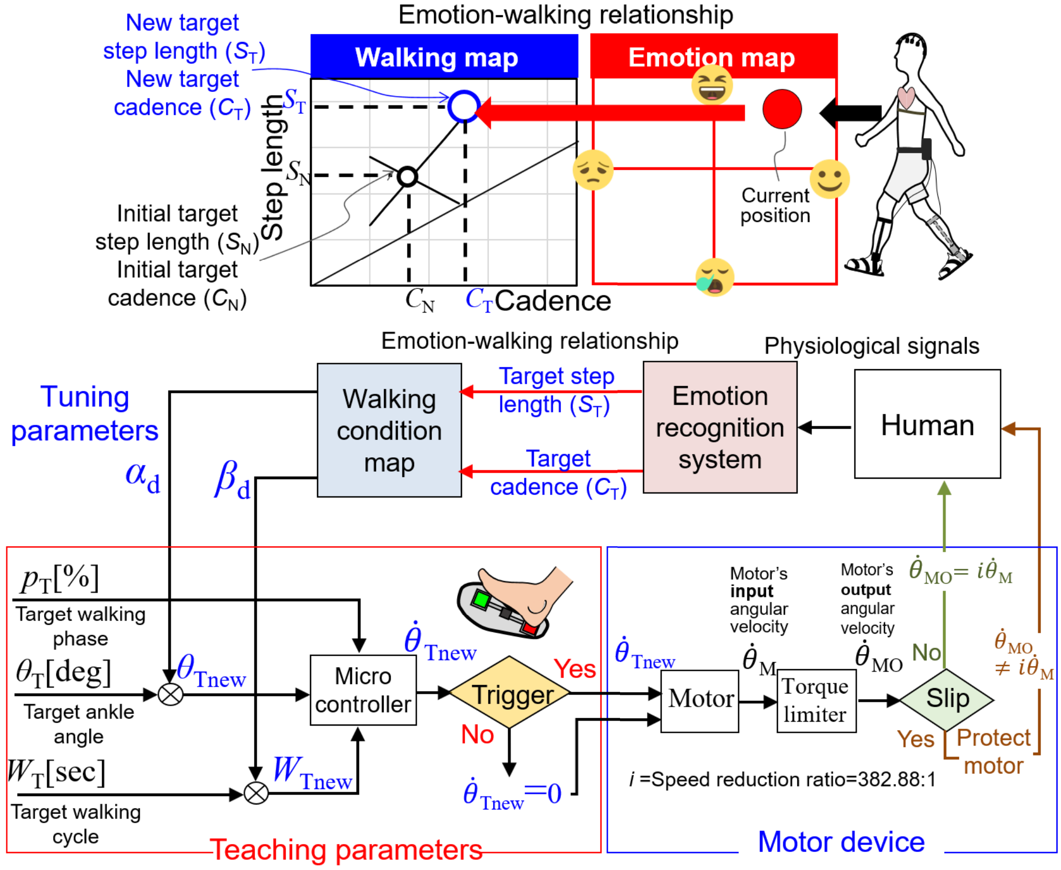


Figure 5.9. The actuation procedure of emotion-walking control system.

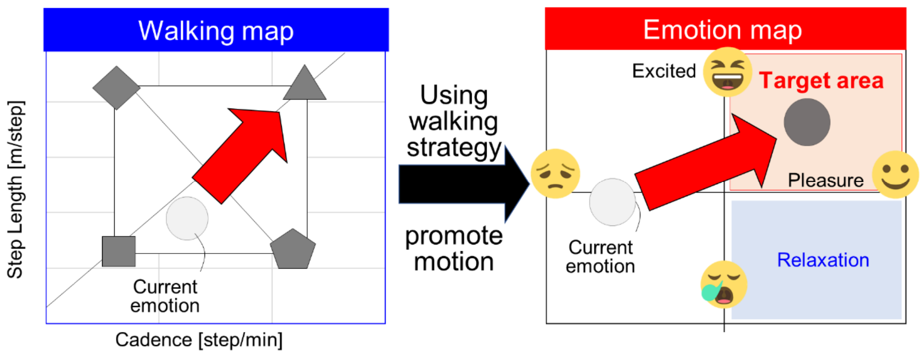


Figure 5.10. Using walking strategy promotes and maintains positive emotion.

5.6.5 First Walking Strategy-Repeated Walking

Owing to the walking-emotion relationship, we observed that the emotion changes are according to the walking behavior changes. We assumed that emotions may be accumulated while walking changes from the current condition to the next condition. A means of maintaining emotion based on repeatedly walking was thus proposed, as shown in Fig. 5.11(a). The monotonous motion would easily reduce the activity of brain, which lead to bored and sleepy. As the results of repeated walking stimulated emotion, four repeated strategies could promote positive emotion (positive slope, direction on the first quadrant), and could reduce the excitement (calm down emotion, direction on the fourth quadrant). For maintaining motivation, not only promote the emotion but also the calm emotion is important during exercise. Therefore, this method concerned to use a different repeated strategy to maintain the freshness and positive mental condition of the users during the walking exercise. While using this strategy with the device, the emotion-walking system would follow the current emotion then perform the suitable repeated condition. For instance, if the users' emotion is recognized on un-pleasure and unexcited (third quadrant), the system gives the strategy of the repeated fast walking for emotion promotion (first quadrant). Contrarily, when emotion located in the first quadrant for a long time, the system gives the strategy of the repeated slow for affective calm down.

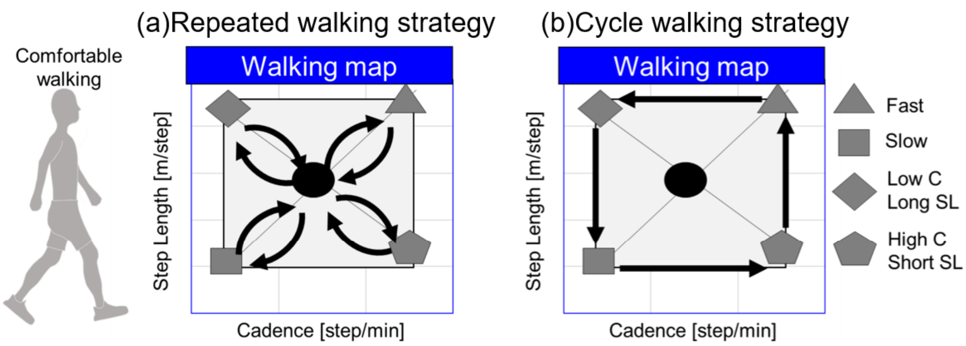


Figure 5.11. Walking strategy for emotion promotion. (a)First walking strategy-repeated walking. (b)Second walking strategy- cycled walking.

5.6.6 Second Walking Strategy- Cycled Walking

To promote emotion effectively, the cycled walking strategy was proposed. The idea is born by classical music. When listening to classical music, there are four movements of a symphony. In the first movement, the major key starts to be played, which can make pleasure feelings. Then, the second movement shows the minor key to make the people feel unpleasure and unexcited. After that, the third movement shows the minor key again to give people feel sad. Finally, the major key shows again in the four movement (Fig. 5.12), which let people be obtained the promotion of positive emotion, as shown in Fig. 5.11(b). The classical music exhibits emotion sequences: 1. Positive 2. Negative 3. Positive, in the symphony. Using this concept, the author proposed the cycled walking strategy to make people to be promoted to the positive emotion. As the results indicated by the cycled walking stimulated emotion, when cycled walking in case 2 and 3, the users' emotions became unpleasant with unexcited (third quadrant). However, when walking in case 1, the users' emotion was promoted strongly compared with using repeated fast walking (comparison of average emotion questionnaire results). Additionally, when reviewing the detailed results by this method, the users would receive emotional iteration in positive and negative. We believed that the user obtained the same emotional assumption of classical music listening. Thus, while using this strategy with the device, the experiments selected to use case 1 (start from "fast walking" and rotated by counterclockwise, end at "fast walking") for promotion emotion of users. They could thus attain different emotional stimuli to further achieve more high-level promotion.

Figure 5.12. Classical music (the four movements of a symphony).

5.7 Proposed an Emotion Promotion Control Method Using Walking Strategy

The mean purpose of using this emotion-walking assistive system is to make the users' emotions be promoted more deeply and maintained a longer time. On the 2D emotion map, 1st and 4th represent the positive area. We hence proposed the method to promote and maintain the emotion of the users at these areas. The users thus are obtained more effectively dual assistance. From the walking strategy, we observed that the users' emotions could be promoted to the first quadrant (pleasure and excitement). The emotion located at the fourth quadrant (pleasure and unexcited) which is important owing to the corresponding to relax feeling. It could make the users maintain motivation. Therefore, an emotion promotion control method using walking strategy was proposed. The control strategy is indicated in the Fig. 5.13. This method employed two evaluation of emotion-walking relationship (section 5.5) and walking strategy (section 5.6.4).

The emotion recognition system is used to recognize the user's current mood. This system mainly is divided into two condition, one is positive area (1^{st} and 4^{th} quadrant) another is negative area (2^{nd} and 3^{rd} quadrant).

When entering the system, the current emotion will be measured, and then the system will analyze users' current feelings further judge its goal. After that, the system will propose the walking strategy for the users to change emotion, finally, the last emotion evaluation will feedback to the emotion recognition system. It is one complete procedure as indicated above.

(1) If t

- (1-1) if the time less than 5 min, the system advice current condition can relax deeply by using repeated walking short step length and high cadence;
- (1-2) if time more than 5 min, the system believes the users might be easily feeling sleepy. It, therefore, use the repeated walking of fast to strongly evoke and promote emotion.

(2) When the current emotion located at the first quadrant (pleasant with excited),

- (2-1) if the time less than 5 min, the user might be starting to feel the excitement, thus, it could be promoted deeper by using the peaceful gait of repeated walking of slow to gradually promote the emotion.
- (2-2) if the time more than 5 min, the users may be over-excited too long time which wound make them fatigue easily. Thus, it is better to reduce their arousal emotion by using repeated walking of long step length with low cadence for calm down feeling.

The article expressed that when people located at the high-intensity emotion, which will lead to tired and mental fatigue [141][142]. Also, previous studies had examined the LF/HF to respond to user arousal emotion. From the physiological signals results, the LF/HF indicated that the most intensity signals located at the time period about 3 to 6 minutes when the subjects were emotionally stimulated [140]. After that, LF/HF had decreasing intensity. We thought the subjects should have a short rest period, they then can start again. It indirectly indicated that, if high arousal emotion maintains a too long time, people may happen the tired and fatigue condition as previous article mentioned [141][142]. Therefore, this control strategy selected five minutes as an index to confirm the user's emotion and change their emotions by walking strategy.

(3) While detecting the emotion located at "unexcited with unpleasant and unexcited but neural emotion in pleasant axis", the users will be thought they are currently very uncomfortable and sad. The system hence proposes the most strongly promotion method of cycled walking in fast. This method could make people improve negative mood strongly.

(3-1) When the current emotion located at the unpleasant with the neutral mood in excitement, to make the user to quickly elevate emotion, the system proposes to utilize the method of repeated walking in fast.

(3-2) if the user feel the emotion in high arousal and without any pleasant, it represent the users might angry. Thus, the repeated waking in short step length and high cadence that could validly reduce excitement and promote emotion to the positive emotion.

(4) By tuning this control method, the users' emotional state would be updated and then being recognized again for the judgement of the next condition. The mainly purposes of this method are promote and maintain emotion by using these walking strategy.

This control strategy is to make the user's emotions be affected on the positive emotional area, however, in order to avoid the user's emotional excitement for too long, the system would implement the walking strategy to reduce their excitement and at the same time maintain a happy mood.

From the cycled walking experiment, we thought that the most effective assistance gait strategy is: "1.start from normal walking 2.fast walking 3. by c.c.w direction to walk each condition 4. end of fast walking". Additionally, in the concept of cycled walking, the emotion should obtain the negative emotion then giving positive emotion, the users can thus achieve more enhanced emotion in a positive state. Even though this strategy showed good effects of promotion, however, cycled walking methods existed the problems which would make the users receive greater negative emotion. It is unsuitable to maintain the positive emotion, thus, the cycled walking strategy was only applied for promotion emotion in the control method.

The control method can be applied to the rehabilitation center, and the physical therapist can real-time observe the emotional changes of the subject, and then help the user adjust the device to keep the psychological state positive, and finally reach the goal of daily-progress in rehabilitation.

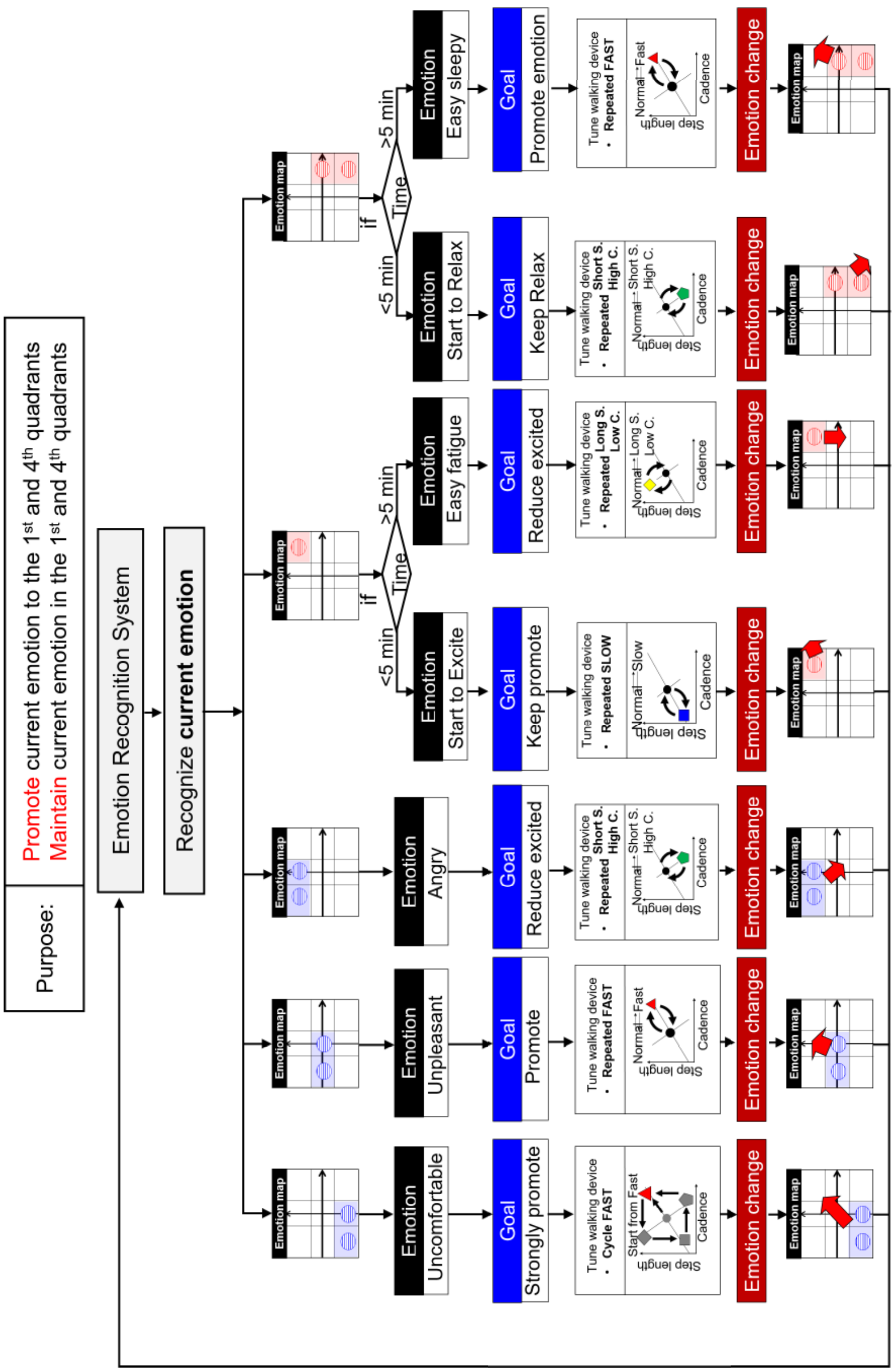


Figure 5.13. Control strategy of emotion promotion applying walking strategy to a walking device.

5.8 Experiment and Results

5.8.1 Personal Walking Region on the 2D Walking Condition Map

To explore the relationship between walking and emotion, an experiment was prepared. We used the personal walking condition to stimulate emotion of the people. Step length and cadence were employed in this experiment for controlling the walking condition. On the side of the treadmill, we prepared the markers that attached on a ruler. A camera was used to record the current walking condition, then showed the live video on the monitor. Additionally, we prepared the metronome to play a tempo. Therefore, participants could watch the monitor to control their step length and listen to the tempo to control their cadence at the same time. Participants could adjust the walking speed of the treadmill for matching the step length and cadence. During the walking, they were required to equip the heartbeat and brainwave detectors. The experiment scenario is shown in Fig. 5.14. Seven participants were invited to join in the experiment (height: 176.7±6.2 [cm] and weight: 72.7±6 [kg]).

In this experiment, we focused on exploring the relationship between walking and emotion. However, excessive walking is possible to affect people emotion. To prevent that, we proposed a means of walking experiment named personal walking region (PWR) to define the personal walking condition for each participant. Dal et al. (2010) [102] found different walking condition will affect the different energy consumption. We believe that PWR can make people emotion and energy consumption stable. The procedure of PWR is the following:

1. The participants were required to comfortably walk in three speeds (slow, normal, and fast). Then, on the 2D walking condition map, the personal preferred walking ratio (PPWR) can be decided by curve fitting.

2. PWR was defined by the position of slow and fast walking.

3. Decide the vertical ratio of PPWR. On this ratio, we can determine two walking conditions, there are "long step length with low cadence" and "short step length with high cadence." From these steps, we could thus determine the PWR of each participant, and obtain five specified walking conditions, there are, slow, normal, fast, long step length-low cadence, and short step length-high cadence, as shown in Fig. 5.15. The procedure was conducted before starting the experiment. Seven subjects' PWR is shown in right figure of Fig. 5.15.

Figure 5.16 indicates the walking-emotion relationship experimental protocol. The emotion

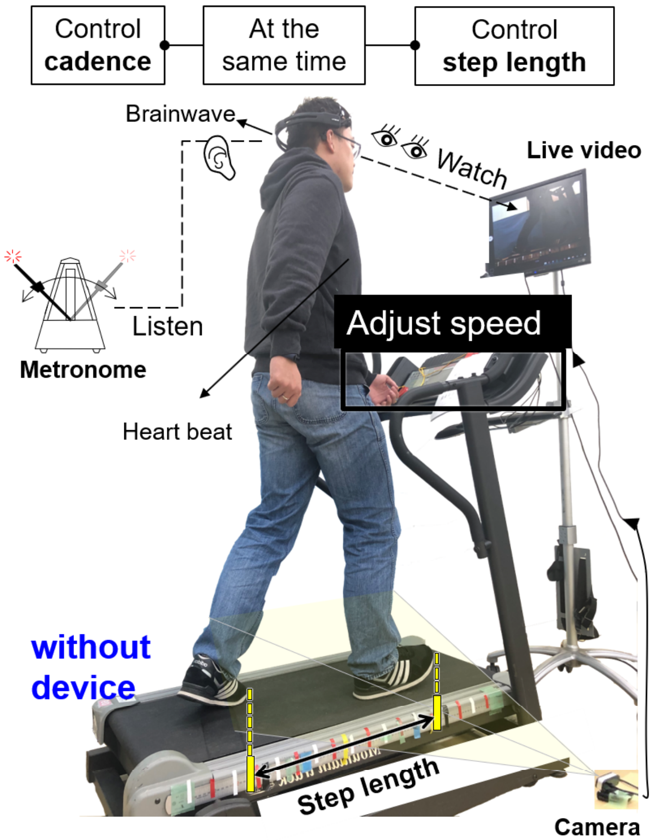


Figure 5.14. The emotion-walking relationship experiment scenario.7 participants were invited to join in the experiment (height: 176.7±6.2 [cm] and weight: 72.7±6 [kg])

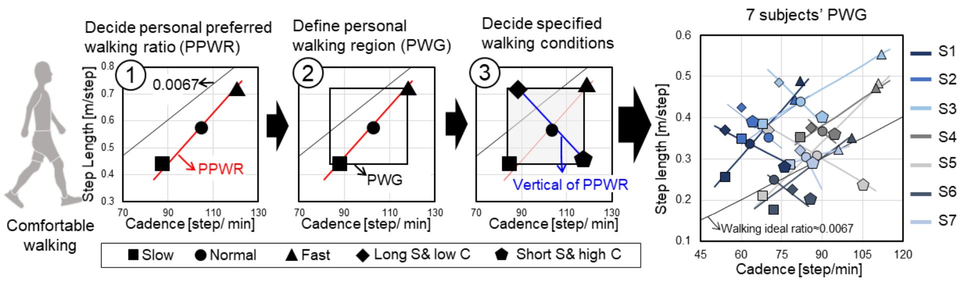


Figure 5.15. Determine the personal walking region (PWR) and the results of seven subjects PWR.

of human is susceptible. If t -

tration. Thereby, it is hard to confirm the walking-emotion relationship. In our experiment, we suppose to walk for 30 secs that is suitable to obtain the relationship between emotion and walking.

1. Subjects walked by following the for 30 sec.

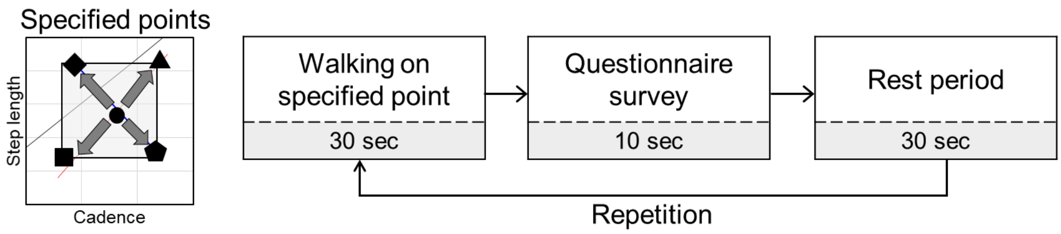


Figure 5.16. The walking-emotion relationship experiment protocol.

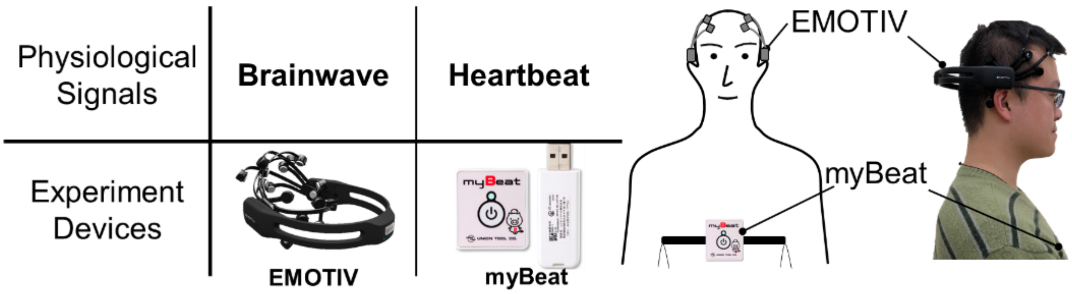


Figure 5.17. Experimental devices for detection of physiological signals.

2. After completed walking condition once, they filled out the questionnaire to report their subjective emotion for 10 sec.

3. They had a rest for 30 secs.

In this experiment, we utilized the electroencephalogram (EEG) and electrocardiogram (ECG) as the physiological response connected to the emotion of people. The EEG and ECG devices are same as chapter 4 as shown in Fig. 5.17. Furthermore, in order to confirm the subject's walking condition, we employed a compact lower limb joint measurement device, which mentioned by Section 3.5.5.

5.8.2 Results of Emotion-Walking Relationship

Seven subjects' gait data are indicated in Table 5.1. We recorded the questionnaire results corresponding to walking conditions, as shown in Table 5.2. The results of normal walking were as initial emotion in the experiment; then, each specified walking condition was as final emotion. From the walking condition change, we could observe the vector which determined the relationship between walking and emotion. The findings showed that the emotion was changed by different walking conditions. Under the specified walking condition, it mainly could be divided into two walking behaviors, there are “walking on the PPWR” and “walking on the vertical of PPWR.”

Walking on the PPWR: First, from normal to fast (red arrow), we observed that subjects felt arousal emotion was stronger than valence emotion. Furthermore, the average results revealed the emotion was elicited to the first quadrant which represents the perception of positive arousal and positive valence that are corresponding to the walking in fast. Second, from normal to slow walking (blue arrow), most of the subjects felt negative feeling in the arousal and pleasure aspect. Moreover, the average results revealed that the slow walking mitigated the excitement and pleasure.

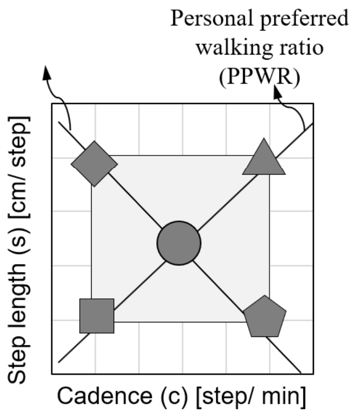
Walking on the vertical of PPWR: First, from normal to long step length-low cadence (yellow arrow), the emotion vector pointed to the third quadrant which means the negative arousal emotion and negative pleasure emotion were evoked., We also observed the people felt unexcited with the slight unpleasure while walking at this gait. Second, from normal to short step length-high cadence (green arrow), the findings showed that the slightly unexcited was elicited, but the perception of the valence remained at the same level.

Additionally, the emotion recognition results are exhibited in Table 5.3. According to the average results of the recognition system (Table 5.4), the tendency of it has a similarity to the questionnaire results. Walking easily makes the intense motion that causes the detectors to receive the disturbance and noise; whereby, some results showed a different tendency to the questionnaire responses. However, we still believe that our recognition system has a high possibility to apply in the actual situation. For the future works, we will improve the performance of the developed emotion recognition system.

T

	Normal			Fast			Slow		
	C. [step/s]	S. [cm]	V. [km/hr]	C. [step/s]	S. [cm]	V. [km/hr]	C. [step/s]	S. [cm]	V. [km/hr]
S1	63	33.7	1.5	90	52.9	3.2	54	25.6	0.9
S2	57	40.8	1.7	71	43.8	2.2	49	40.3	1.4
S3	72	25	1.3	102	36.2	2.5	72	17.7	0.8
S4	84	30.5	1.6	90	28.6	2	78	32.2	1.3
S5	82	43.9	2.5	112	55.4	4.5	68	38.5	1.7
S6	88	30.9	2	111	48.5	3.8	68	21	1.3
S7	70	35.4	1.7	80	44.4	2.6	60	34.9	1.3
	Long S. -low C.			Short S. -High C.					
	C. [step/s]	S. [cm]	V. [km/hr]	C. [step/s]	S. [cm]	V. [km/hr]			
S1	57	37	1.4	76	27	1.3			
S2	55	43	1.6	59	39	1.5			
S3	65	27.5	1.2	86	20	1.1			
S4	82	32	1.7	86	29	1.7			
S5	74	48.5	2.5	90	40	2.5			
S6	70	37	1.9	106	24.5	2			
S7	60	42.5	1.7	75	32	1.6			

T



Walking condition map	Subject	Personal preferred walking ratio (PPWR)	Vertical of PPWR
(see map above)	S1	s=0.748c - 14.172	s=-0.334c + 54.748
	S2	s=0.164c + 31.971	s=-1.526c + 127.802
	S3	s=0.497c - 14.41	s=-0.503c + 61.241
	S4	s=0.191c + 13.995	s=-1.31c + 140.534
	S5	s=0.384c + 12.416	s=-0.651c + 97.317
	S6	s=0.641c - 23.56	s=-0.39c + 65.243
	S7	s=0.472c + 5.218	s=-0.53c + 72.468

TABLE 5.3: Corresponding results of walking conditions between emotion response (questionnaire).

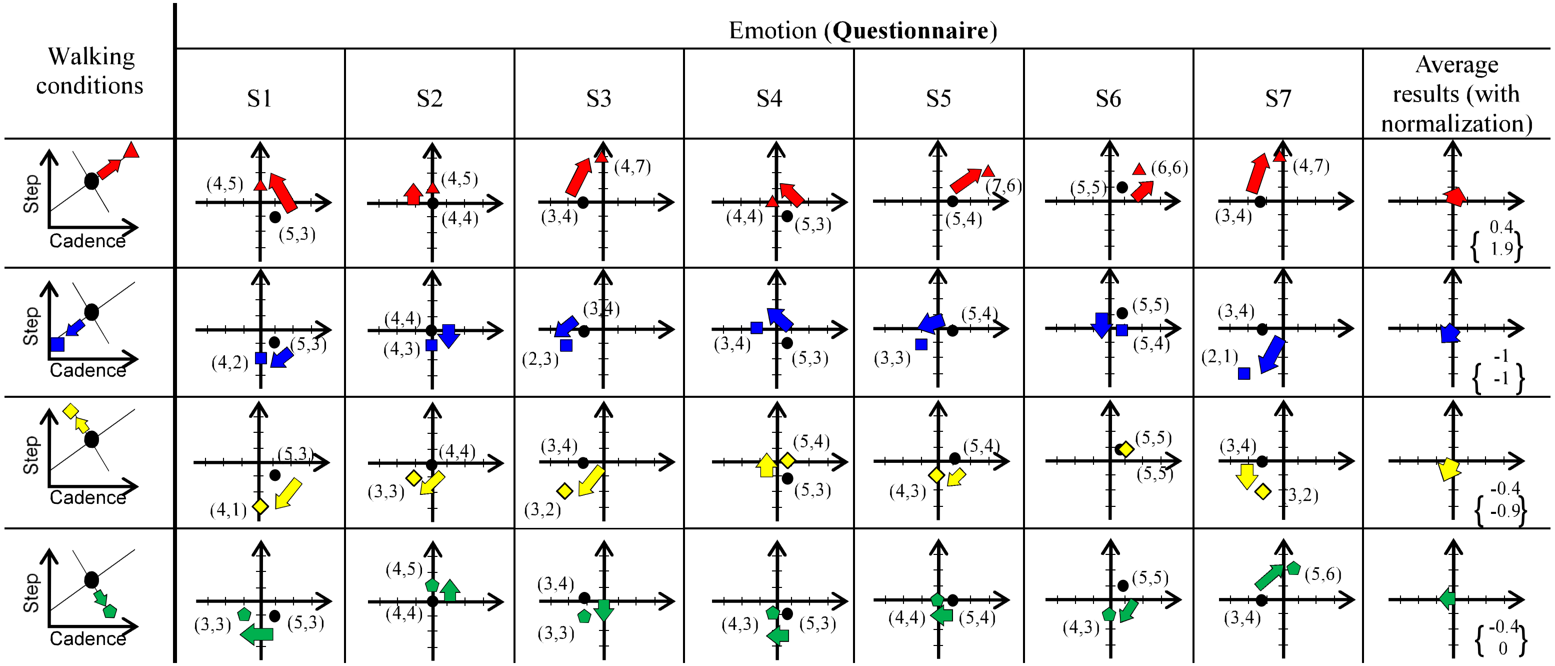
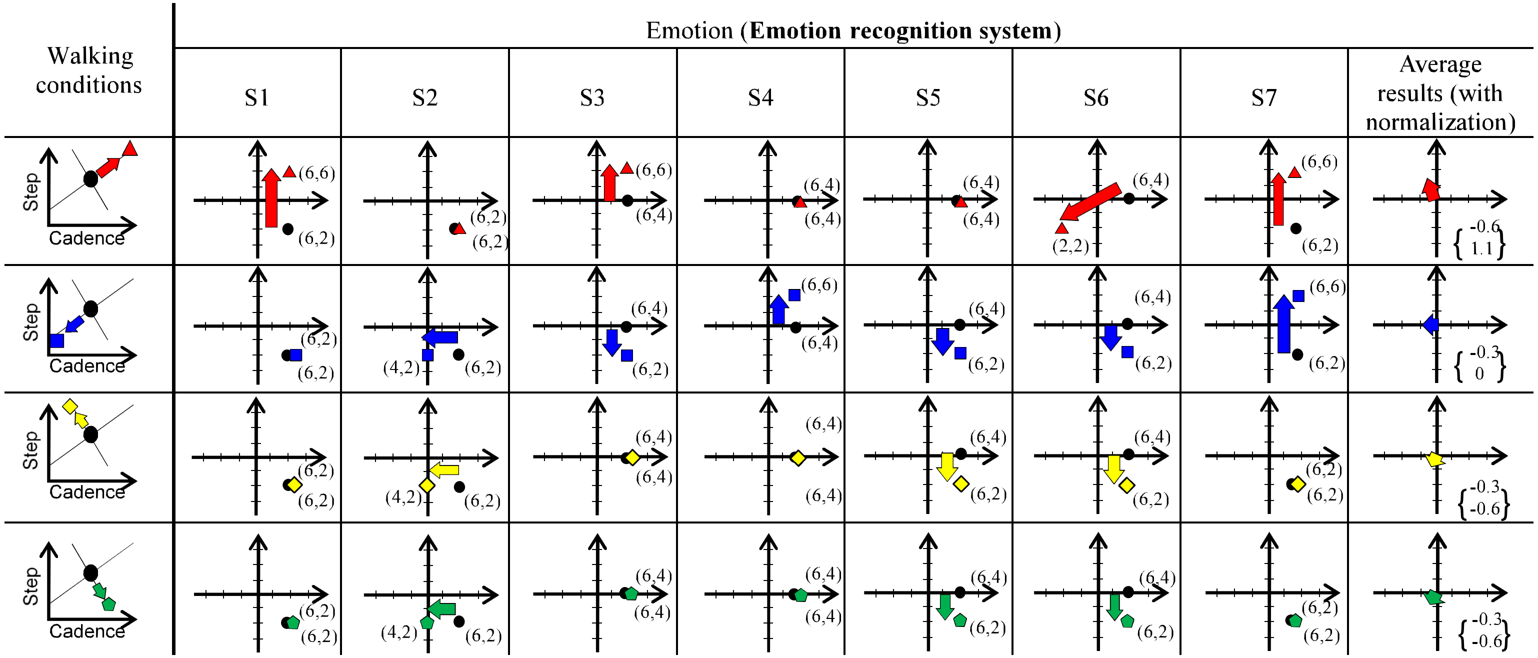


TABLE 5.4: Corresponding results of walking conditions between emotion response (Emotion recognition system).



5.8.3 Repeated Walking Stimulated Emotion Experiment

The experiments were designed, which applied the repeated walking stimulated experiment to maintain the positive emotion of human. We required the subjects to walk repeated between normal and specified conditions for three times. This experiment would like to understand the situation in which emotions are affected due to repeated walking stimuli. The experimental protocol is shown in Fig. 5.18.

1. Subjects walked at normal walking condition for 30 secs;
2. After completing walking, subjects filled out the questionnaire (10 secs);
3. Subjects changed the walking condition to the specified walking point (30 secs);
4. After completing walking, subjects filled out the questionnaire (10 secs);
5. They had a rest for 30 secs.

Each walking condition was conducted three times.

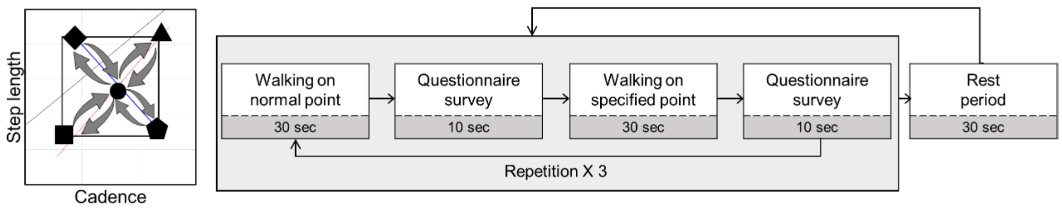


Figure 5.18. The walking-emotion relationship experiment protocol.

5.8.4 Emotion Results of Repeated Walking

Table 5.5 shows the repeated stimulate emotion results, which represents that from the initial emotion to the emotion of after three times stimulated walking. In the previous experiment, we could find the relationship between the walking condition and emotion response. However, we considered how to maintain motivation through walking; thus, a means to maintain the emotion is very important. In this experiment, we applied repeated walking to stimulate the emotion of the subjects, and further observe their emotion changes. Herein, the averaged results were calculated by six participants except for Subject 6. He responded that he had some private issues on mind during experiments; whereby, we thought it may cause the loss of authenticity of the results of the questionnaire; whereby, we did not consider this subject's result. Four walking conditions were conducted repeatedly.

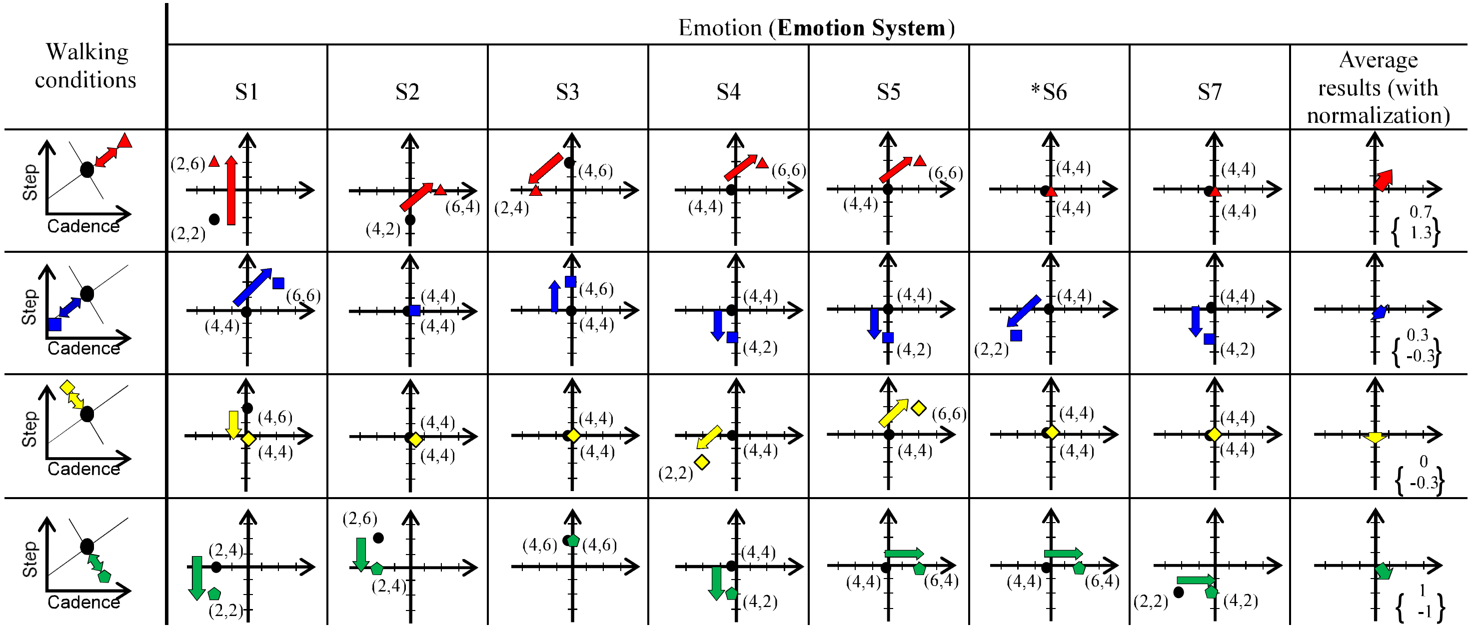
First, repeated walking from normal to fast, the averaged results showed that the emotion was stimulated to the first quadrant. It means the positive emotion was evoked via repeated walking. We observed the people's valence emotion was stronger than arousal emotion. Second, repeatedly walking from normal to slow, the emotion was also stimulated to the first quadrant. However, the positive emotion was only slightly affected. Third, repeatedly walking from normal to the long step length with low cadence, the results indicated the unexcited emotion with slight pleasure emotion was finally evoked after repeated stimulated. Forth, from normal to the short step length with low cadence, the averaged emotion exhibited that the only negative arousal emotion was affected. It means that the emotion could be calm down after using this walking changes. The emotion recognition results are displayed in Table 5.6. We observed that the average results of the system have consistent tendency with the questionnaire results. By using these results, a new method considered the affective of people together with a device is proposed to maintain motivation.

TABLE 5.5: Repeated stimulated results of walking conditions between emotion response (questionnaire).

Walking conditions	Emotion (**Questionnaire**)							
	S1	S2	S3	S4	S5	*S6	S7	Average results (with normalization)
Step, Cadence	(3.6,4.0) (3.8,2.2)	(5.3,5.5) (4.2,4.0)	(3.6,4.6) (3.3,4.2)	(5.5,4.5) (4.0,3.5)	(4.4,4.8) (4.0,4.0)	(3.6,3.8) (1.9,2.3)	(3.5,4.0) (3.5,3.2)	{0.4, 0.7}
Step, Cadence	(4.9,3.7) (3.6,2.8)	(4.3,4.4) (4.0,4.5)	(3.3,4.7) (4.1,3.6)	(4.0,4.0) (4.0,3.5)	(3.9,3.9) (4.0,3.1	(3.8,3.9) (2.6,3.2)	(4.0,3.5) (4.2,3.5)	{0.2, 0.1}
Step, Cadence	(4.0,3.5) (4.1,2.4)	(4.5,4.6) (4.0,4.2)	(4.2,4.5) (4.3,4.5)	(4.0,4.0) (3.0,1.5)	(3.9,4.2) (4.0,4.0)	(4.2,4.6) (3.9,3.8	(4.0,3.8) (5.0,3.5)	{0.1, -0.6}
Step, Cadence	(4.0,2.8) (4.0,2.2)	(3.7,4.0) (3.1,3.1)	(4.1,5.1) (4.3,5.1)	(3.0,3.5) (4.0,4.0)	(4.1,4.2) (4.2,4.2)	(3.9,4.0) (4.3,4.1)	(4.2,4.7) (4.0,3.5)	{-0.2, -0.1}

*S6 results were not included in the average results for calculation

TABLE 5.6: Repeated stimulated results of walking conditions between emotion response (Emotion recognition system).



*S6 results were not included in the average results for calculation

5.8.5 Cycled Walking Stimulated Emotion Experiment

The cycled walking experiment was prepared to stimulate the emotion of the subjects. They were required to walk for surrounding the personal walking region to complete four specified conditions. This experiment would like to understand the cycled walking whether affects emotions changes. The experimental protocol is shown in Fig. 5.19. The subjects were required to walk at the different initial walking conditions, as shown in Fig. 5.20.

1. Subjects continually walked at initial specified walking condition for 120 secs

2. Every 30 sec checked their emotion response by questionnaire during initial walking period;

3. Subjects walked to the four different specified walking conditions (30 secs),

4. After every walking conditions, subjects would fill out the questionnaire (10 secs);

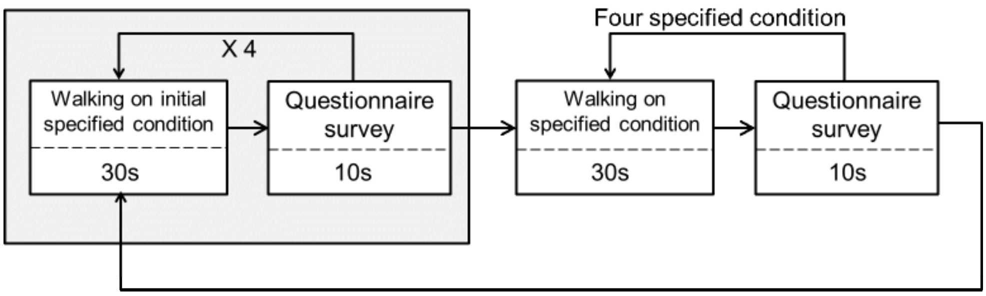


Figure 5.19. The cycled walking experimental protocol.

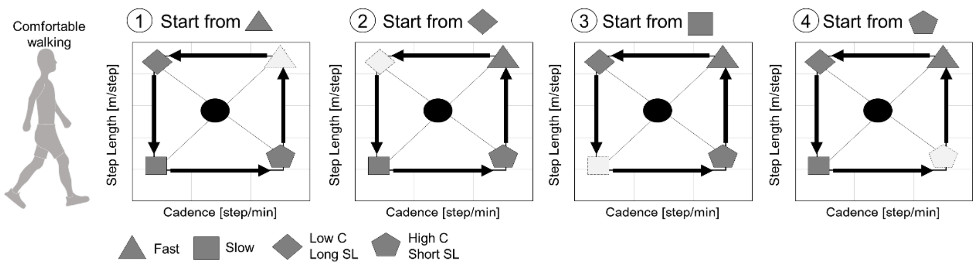
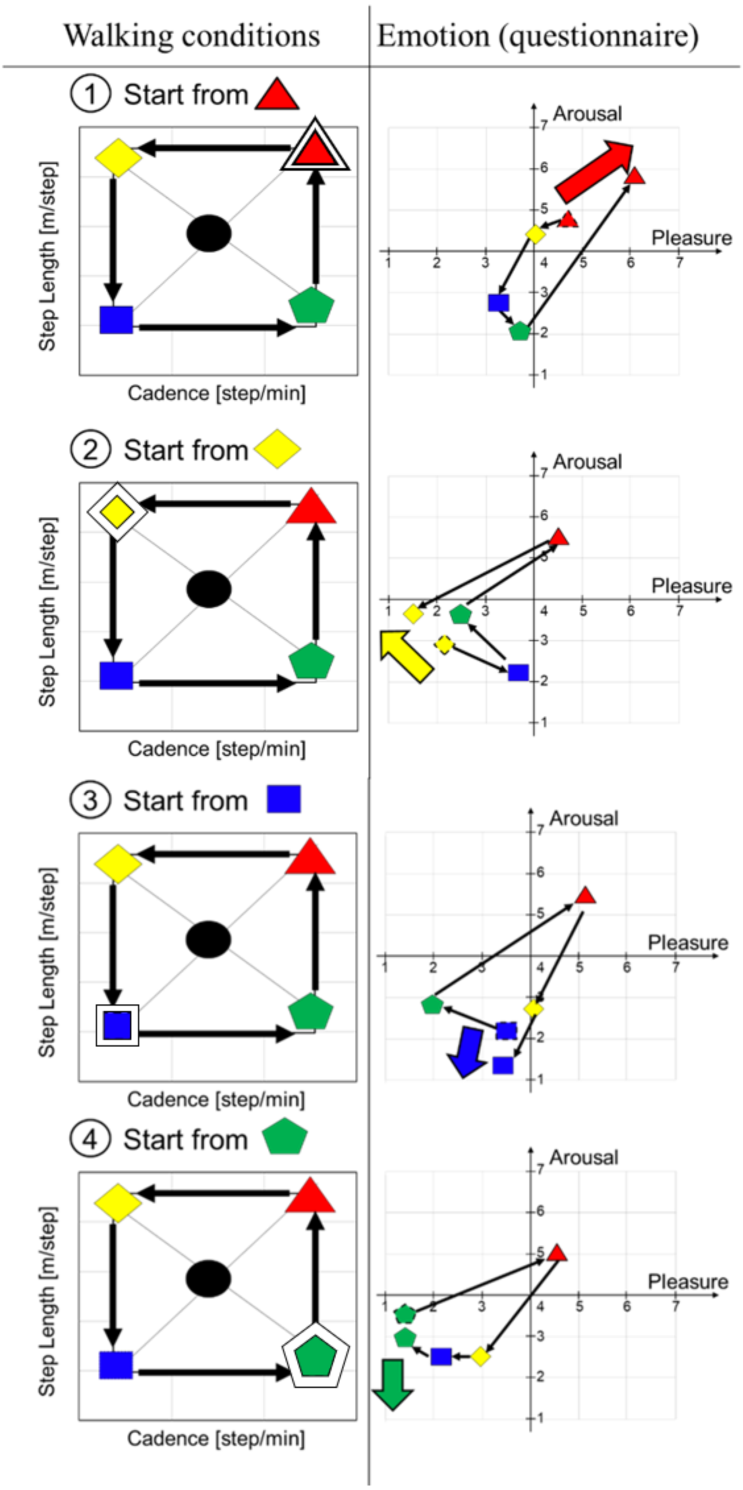


Figure 5.20. Walk at the different initial walking conditions.

5.8.6 Emotion Results of Cycled Walking

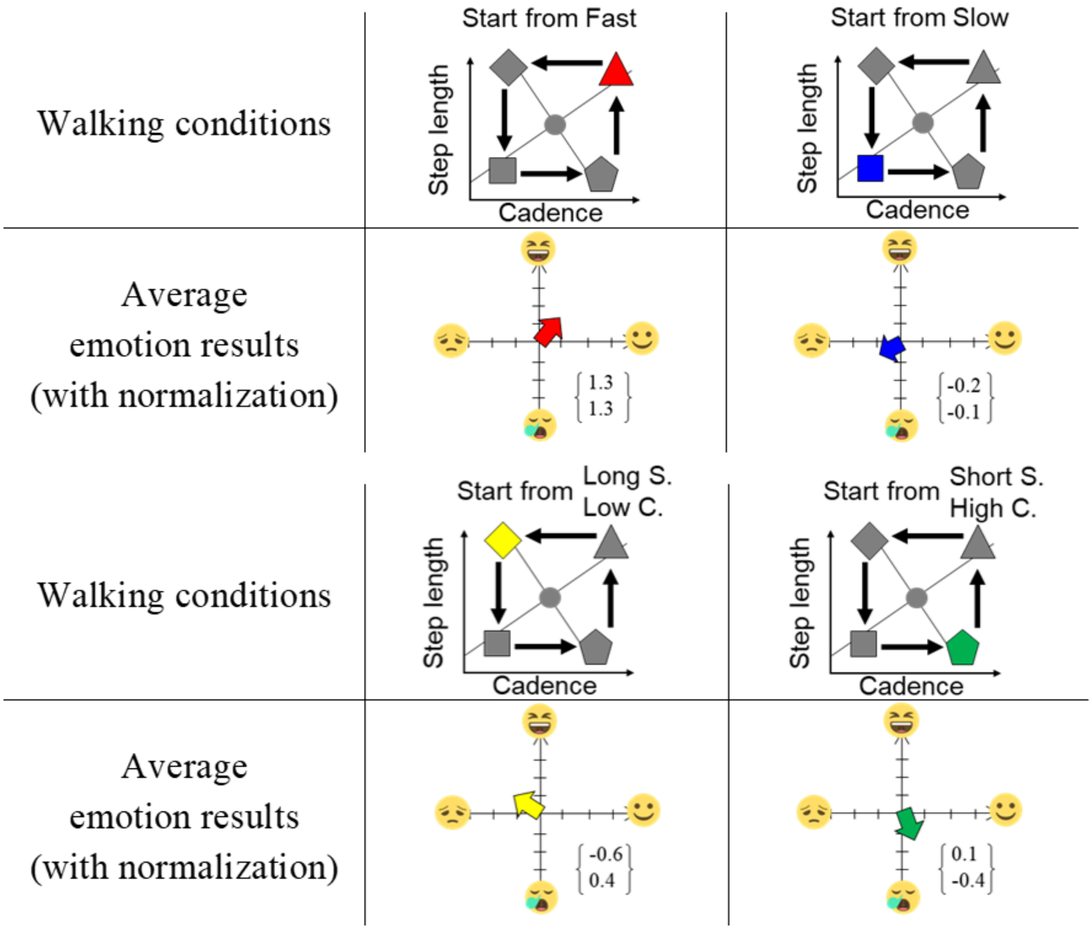
Table 5.7 depicted that the cycled walking stimulated emotion. Table 5.8 indicated the averaged results. Based on the concept of classical music, the experiments were designed. By walking at the different initial specified condition to cycle others specified conditions, the emotion was stimulated to the different states. The finding of case 1 shows that the emotion can be promoted to the first quadrant, which means the emotion finally becomes excited with pleasure. For the case 2, the emotion was stimulated to the unpleasure state. For the case 3 and 4, the finding exhibited that excitability can be alleviated. From four cases results, even though only case 1 can achieve the promotion of positive emotion the author observed that if the gait changes can be finished at fast walking, which can induce emotion promotion. From the results, the author thought that the gait changes strategy existed possibility to make the users emotion promotion. For tuning device, we thought the best cycled walking strategy is:"1.start from normal walking 2.fast walking 3. by counterclockwise direction to walk each condition 4. end of fast walking".

TABLE 5.7: Cycle stimulated results of walking conditions between emotion response (questionnaire).



T

(questionnaire).



5.8.7 Emotion-Promotion Experiments Based on Walking Strategies

Experiments were designed to realize the effectiveness of this emotion-walking system using walking strategies to elicit and promote the people's emotion. We prepared the four different walking experiments:

1.Walking **with device** and **with tuning method** by repeated walking.

2.Walking **with device** and **with tuning method** by cycled walking.

3.Walking **with device** but **without tuning** method.

4.Walking **without device** and also **without tuning** walking condition by strategies (**Free walking**).

We make the subjects to conduct each experiment for 8 minutes, respectively. In this experiment, the subjects had worn EEG and ECG detectors to walk while wearing the assistive walking device. Figure 5.21 shows the actual scenario experiment. Three subjects joined in this experiment. The mean purpose of this experiment is to evaluate the effectiveness of the proposed walking strategies and confirm the user's emotion if promotion.

First, the subjects were required to normal walk for 30 seconds, and the current emotion would be recorded as the initial emotion state.

Second, after 30 seconds, the users were required to walking in specified condition (when walking with device, the device would be tuned to match the required conditions).

The experiment protocol is shown in the Fig.5.22.

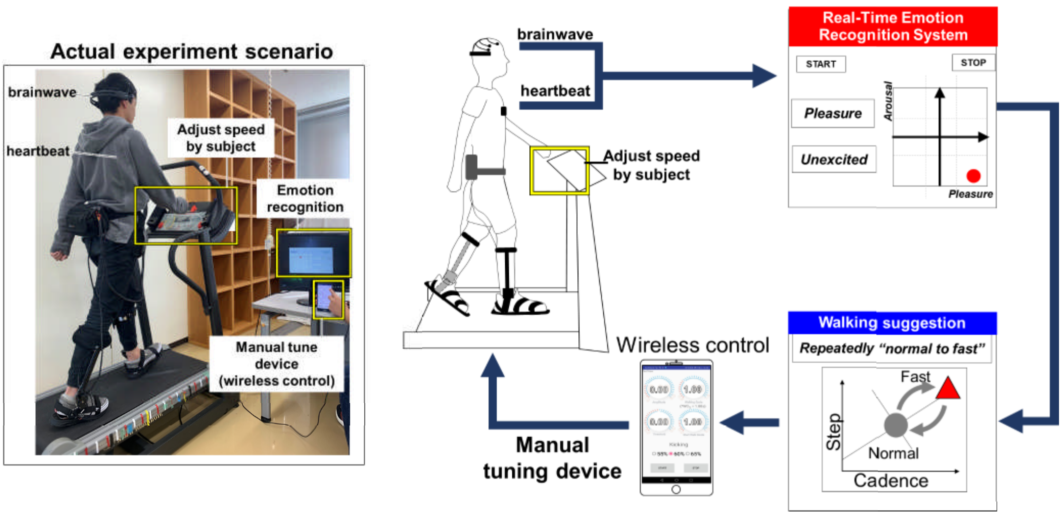


Figure 5.21. Actual scenario experiment (left graph); construction of the experiment procedure (right graph). 3 subjects joined; Age: 24.7 ± 1.7 Height: 175.3 ± 7.6[cm]

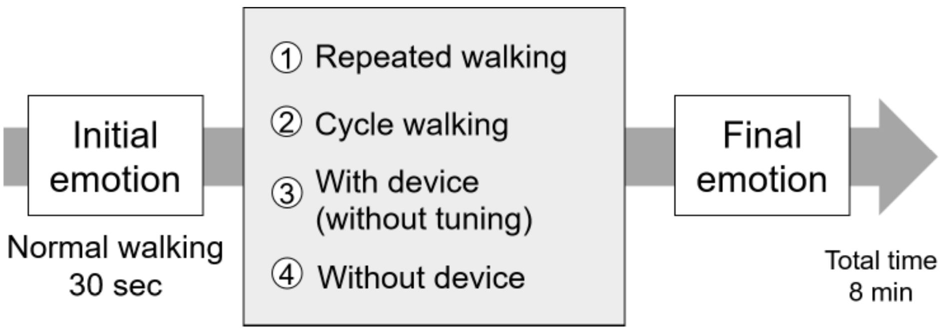


Figure 5.22. Protocol of emotion-promotion experiments based on walking strategies.

5.8.8 Results of Emotion-Promotion Based on Repeated Walking with Assistive Device

Figure 5.23, 5.24, and 5.25 depicted the average results of based on the emotion change (attained by emotion recognition system), the walking device was tuned to control the users walking behaviors, and further promote the emotions. Results of the subject I: The initial emotion showed the "neutral & unpleasure" after normal speed walking period. Based on that emotion, the device tuned the repeated "normal to fast" for purposed on promotion of emotion. After stimulation of repeated walking, the emotion became pleasure. Then, the device tuned the mode of repeated "normal to slow" to attempt on maintaining the emotion. After that, the emotion was kept at the fourth quadrant (unexcited & pleasure). The device based on the judgment further tuned the mode of "normal to fast" which leads to promotion of emotion again. Then, for continuously maintaining the positive emotion, the 4th and 5th respectively used repeated "normal to low cadence with long step length" and repeated "normal to fast." Finally, we observed the emotion of the subject I could be promoted from "neutral & unpleasure" to "pleasure", and also kept the positive emotion during the whole experiment. Results of the subject II: During normal speed walking period (30 sec), the initial emotion exhibited the "unexcited & neutral", which was as the basis for tuning the device. For the promotion of positive emotion, the device was tuned repeatedly walking from "normal to fast" for 90 sec. The emotion of the subject was significantly promoted to excited and pleased. After that, during 90 sec, the emotions of the users can be continuously located at positive state (only pleasure). Based on the last emotion, then the device tuned "normal to slow" for slight promotion of emotion. After 60 sec, the emotion had been promoted, however, it was returned to the neutral emotion after 90 sec. According to the neutral emotion, the device tuned the "normal to fast" in 4th and 5th repeated walking, and the emotion was promoted to the state of excited with pleasure. After the five times repeated walking, the emotion subject II was from "unexcited & neutral" to "excited & pleasure." Additionally, we observed that the subject I's emotion could be continuously located in the positive state. From the final results, the subject's emotion was successfully promoted by using repeated walking strategy with the walking assistive device. Results of the subject III: the initial emotion exhibited the "unexcited & neutral", after the repeated walking strategy, the final emotion was promoted to the "neutral & pleasure".

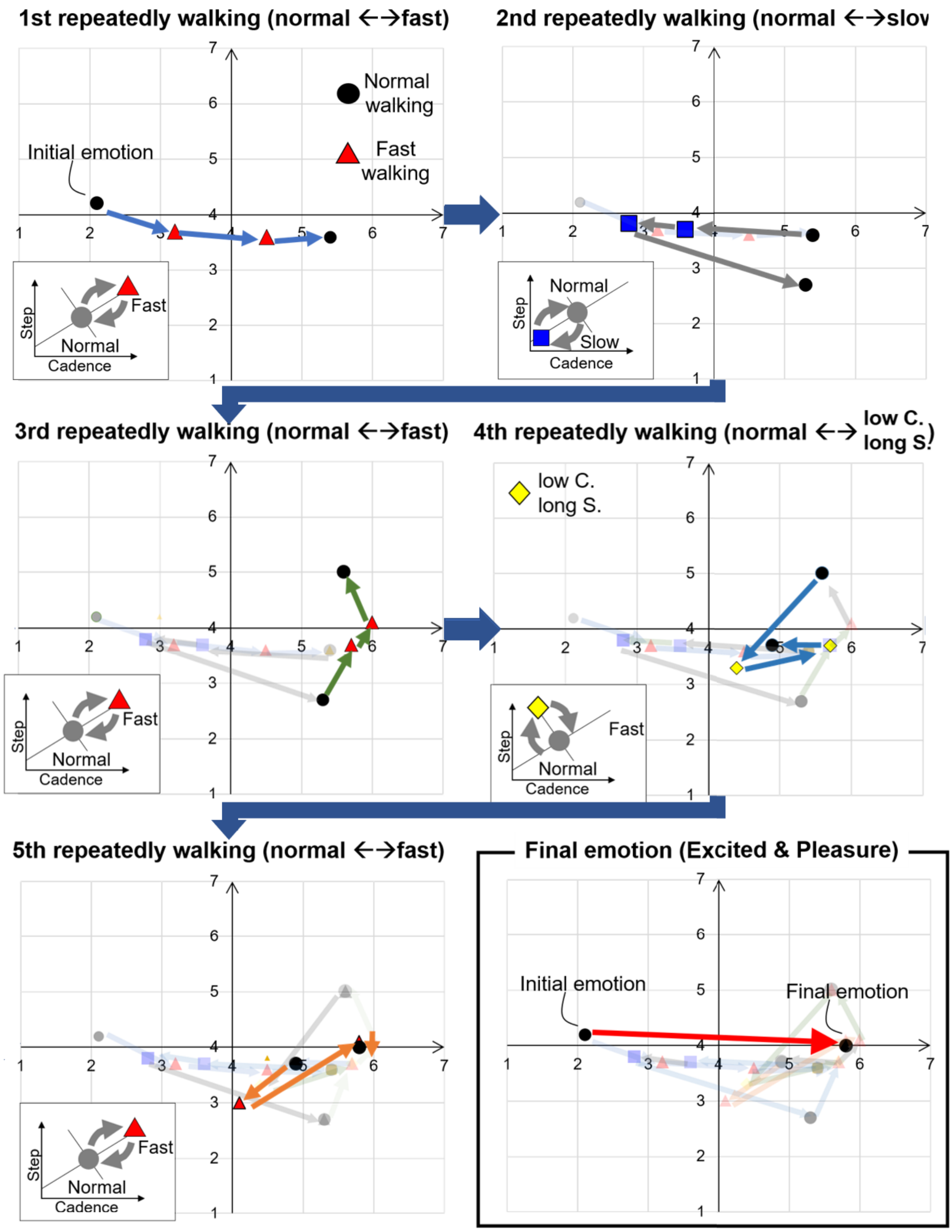


Figure 5.23. Using emotion to tune the device by applying the stimulation of repeated walking method (subject I).

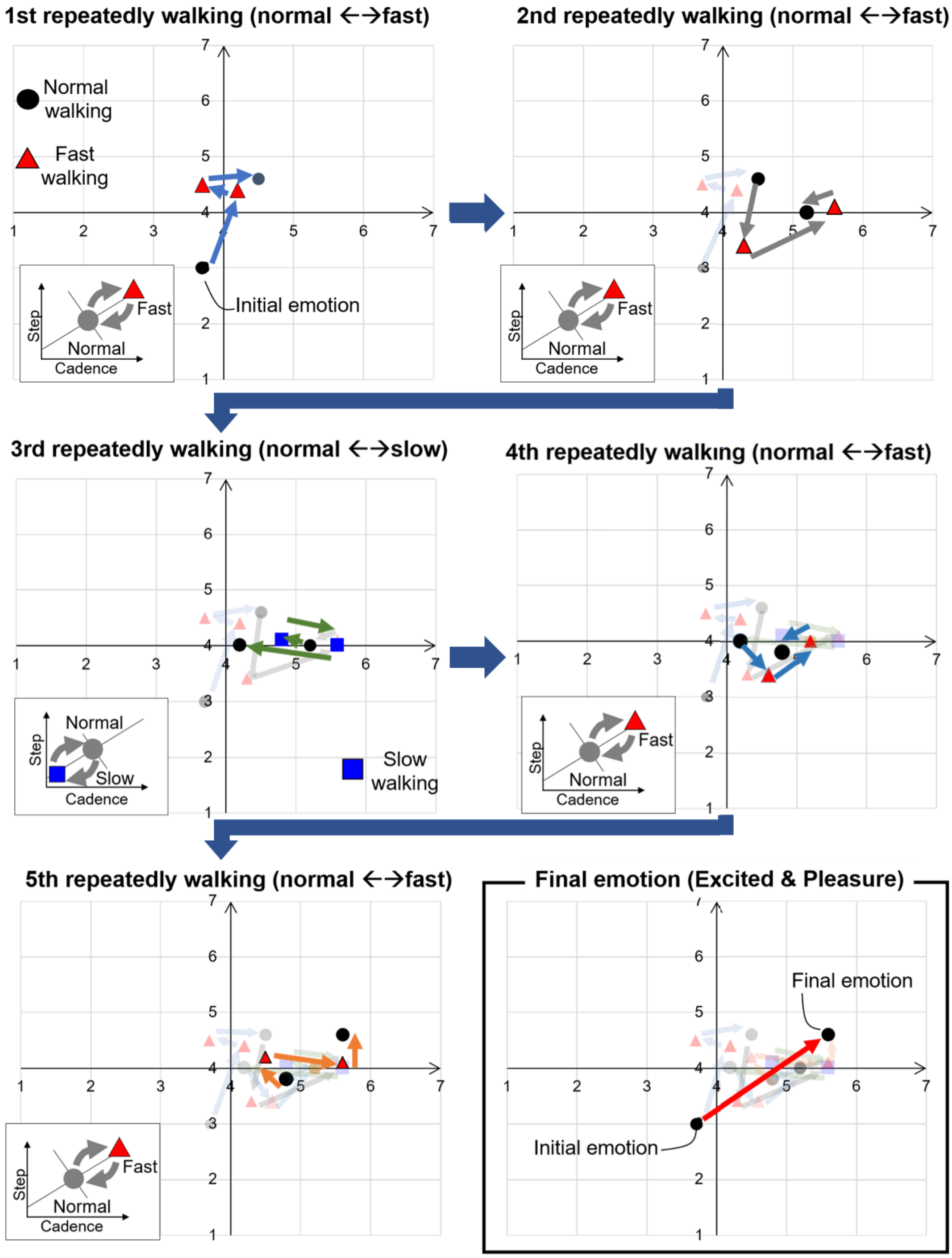


Figure 5.24. Using emotion to tune the device by applying the stimulation of repeated walking method (subject II).

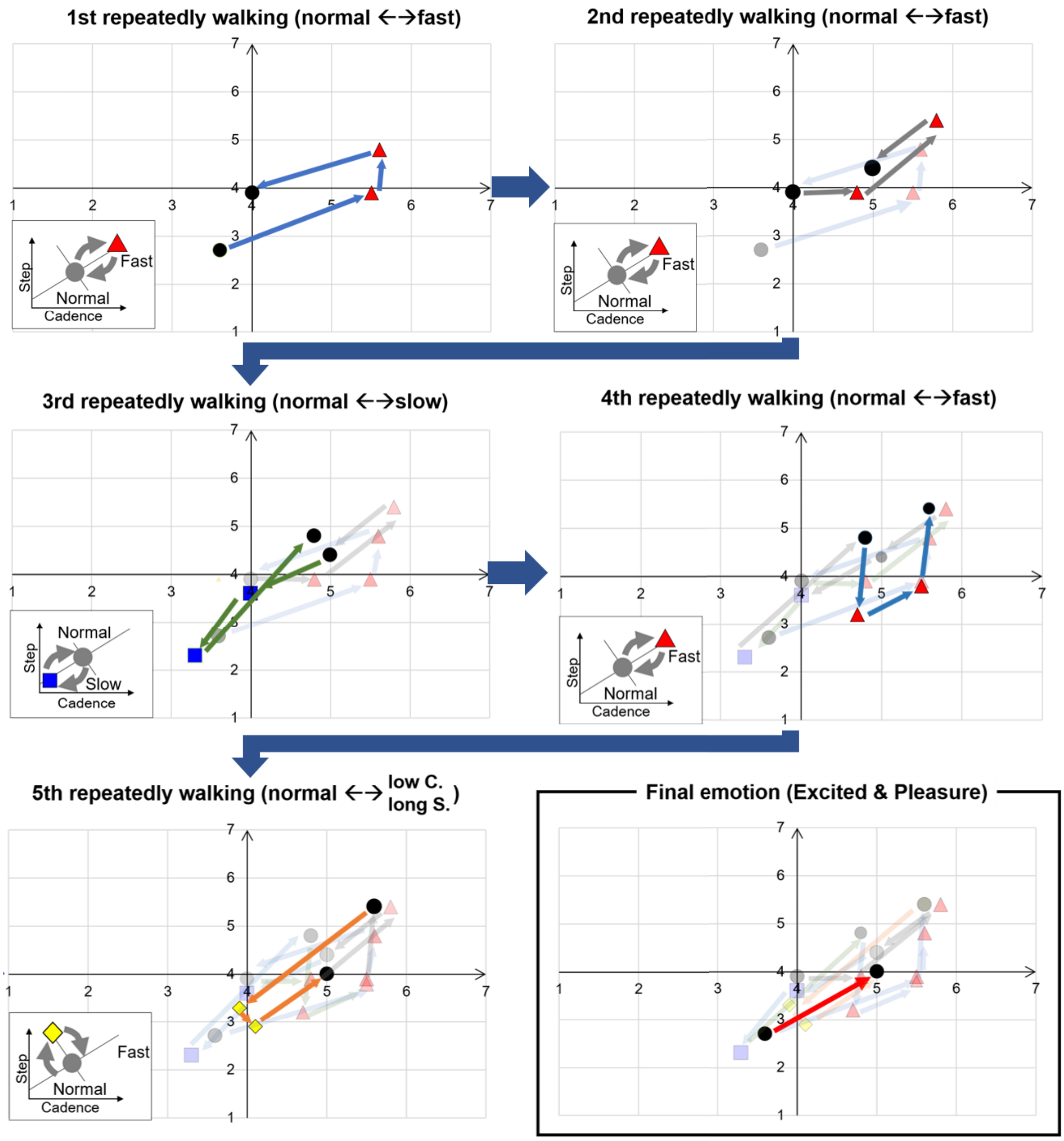


Figure 5.25. Using emotion to tune the device by applying the stimulation of repeated walking method (subject III).

5.8.9 Results of Emotion-Promotion Based on Cycled Walking with Assistive Device

Figure 5.26, 5.27, and 5.28 showed the average results of using the cycled walking strategy to promote the emotion. At the first cycled walking, subject 1 emotion was quickly changed when the condition changed from normal walking to fast walking. Then, with changing the walking conditions, the results showed the emotion would be affected significantly by observing the arrow on each emotion map. Finally, subject 1 emotion was promoted from 4th quadrant to 1st quadrant. In the results of subject 2, at the first cycled walking, we found his emotion was not changed strongly in the first four conditions. However, until the final condition (fast walking), subject 2 emotion received significantly promotion at first quadrant. By continuously using cycled walking, subject 2 emotion was finally promoted from 3rd quadrant to 1st quadrant. For the results of subject 3, most of the emotions were stimulated at the 1st and 2nd quadrant during the cycled walking strategy test. Subject 3 emotion was also finally promoted from 3rd quadrant to 1st quadrant. From each subject's result, we can clearly confirm the final emotion was finally to be promoted to the first quadrant compared with initial emotion. Furthermore, we observed that "fast walking" was sensitive to evoke pleasure and arousal emotion. Thus, by imitating the "classical music rule", the emotion of the subject could obtain significantly promotion. All subjects consistently expressed this walking strategy is quite interesting. They mentioned that the different gait makes them feel freshness even though that gait is not comfortable. Moreover, after completion of the uncomfortable (negative feeling) gait, the comfortable gait occurred in the next condition which makes them feel intense emotion (positive emotion) t

(start from fast, and end of fast), we suggested it is suitable for giving the strongly emotion promotion (when emotions are detected at third quadrant).

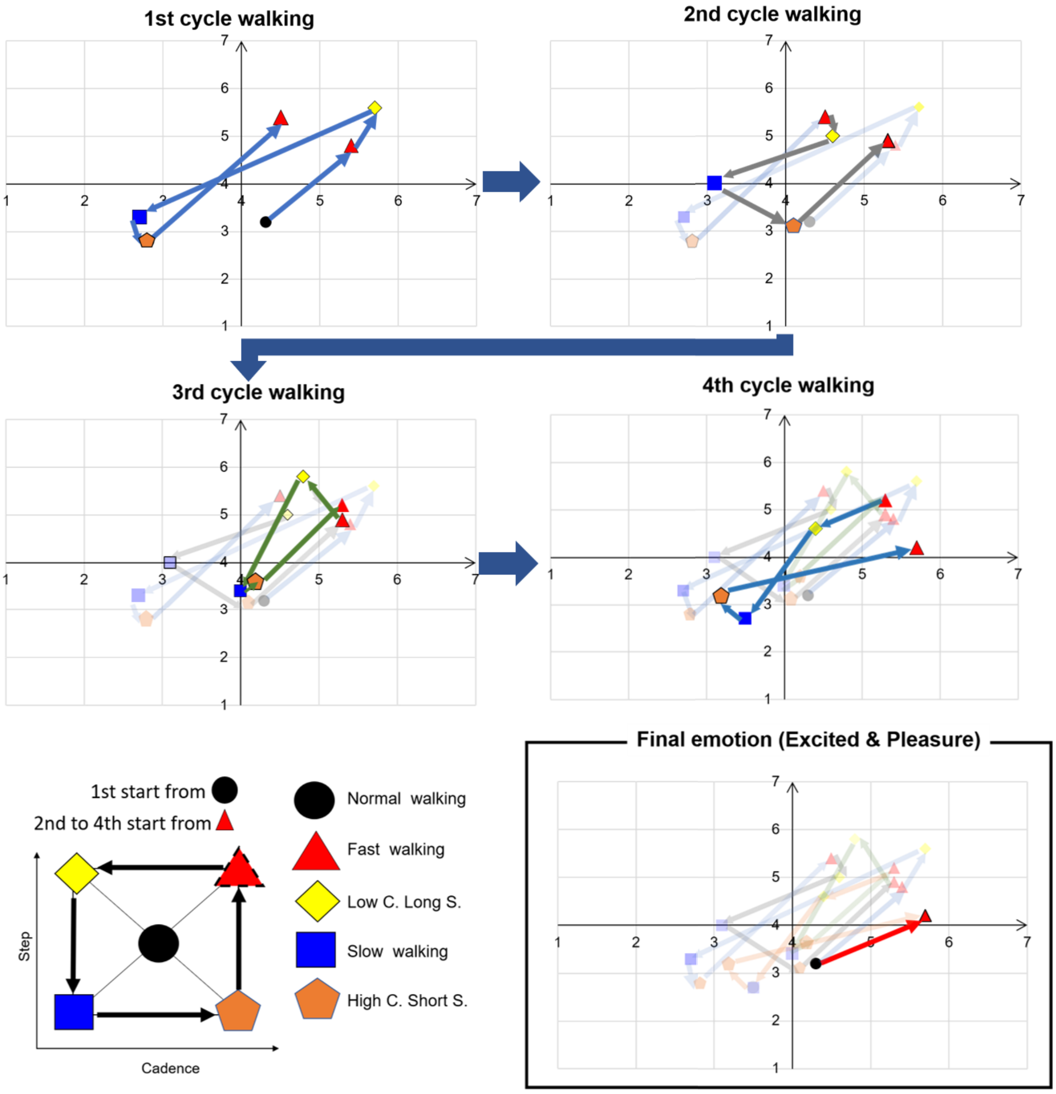


Figure 5.26. Using emotion to tune the device by applying the stimulation of cycled walking method (subject I).

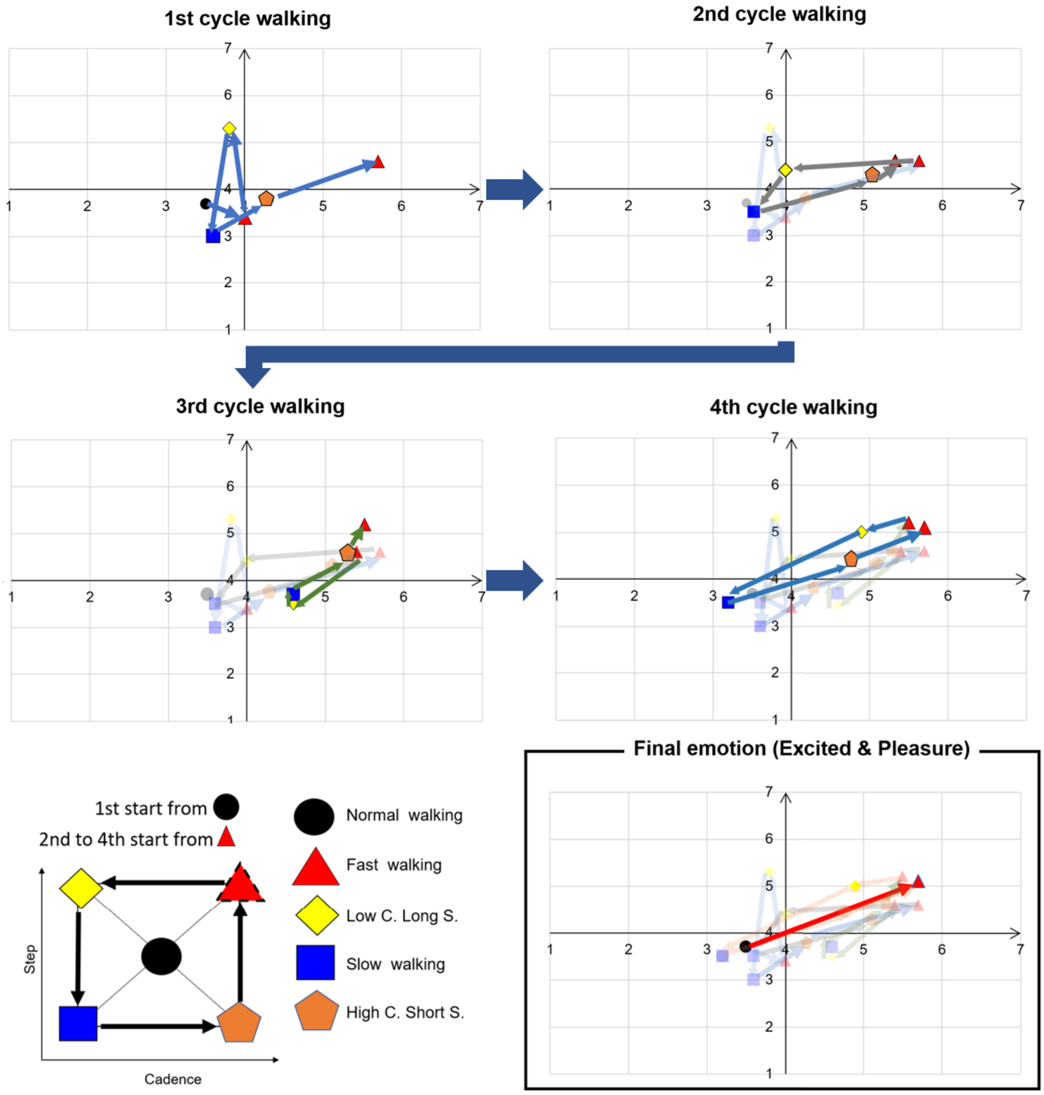


Figure 5.27. Using emotion to tune the device by applying the stimulation of cycled walking method (subject II).

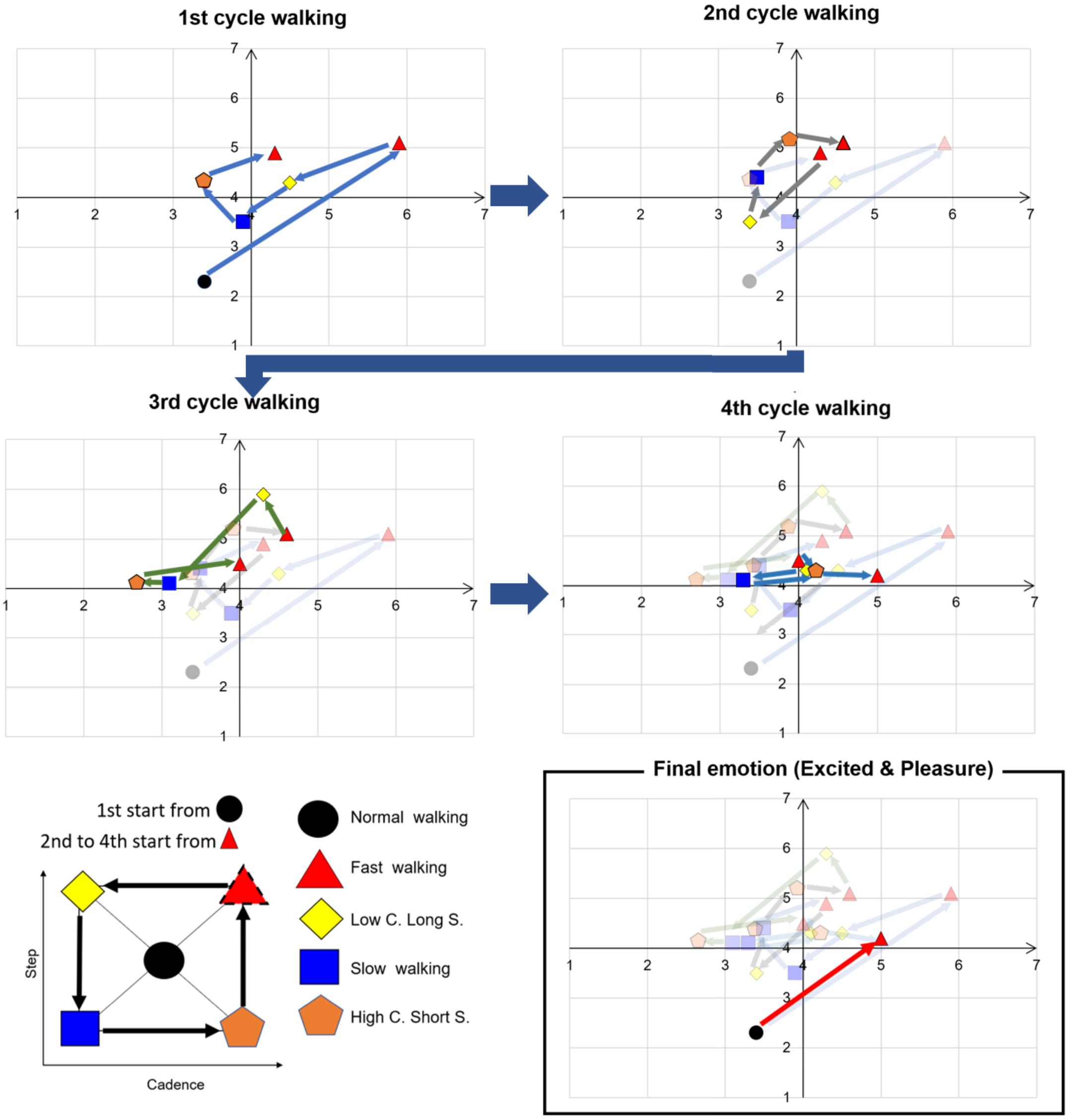


Figure 5.28. Using emotion to tune the device by applying the stimulation of cycled walking method (subject III).

5.8.10 Results of Walking with Assistive Device but Without Tuning Device

Figure 5.29, 5.30, and 5.31 showed the average emotion response of walking with device but without tuning device.The experiment results showed that the final pleasure emotion decreased and the arousal emotion almost unchanged in three subjects. From the oral description of the subjects, they unanimously thought that under a long-time walking, they feel quite bored and don't even want to continue the experiment. Thus, it is very important to tune the device while using device. From above results, the observation shows that without tuning device would decrease the current pleasure and arousal emotion.

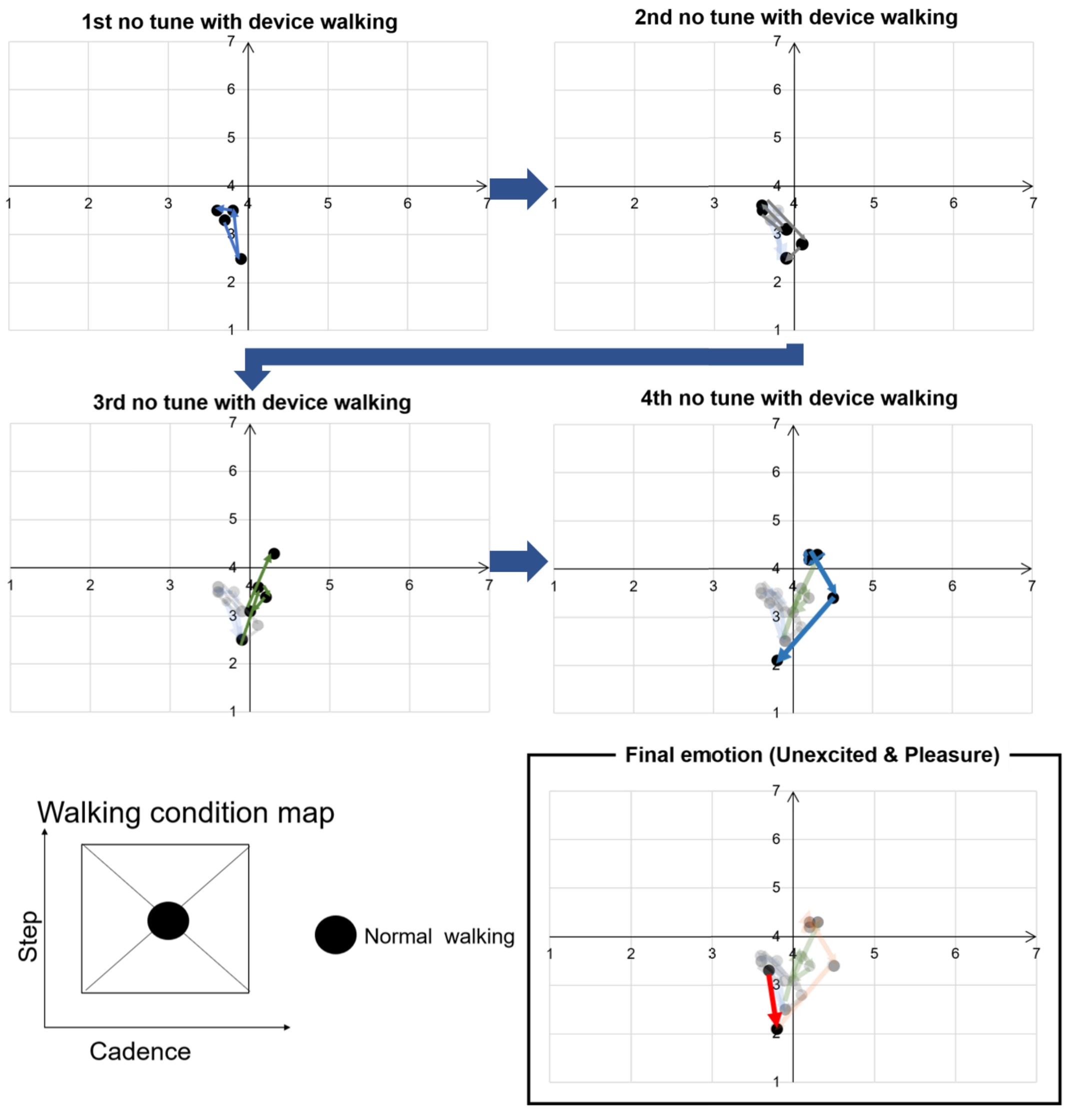


Figure 5.29. Walking with device but without tuning device (subject I).

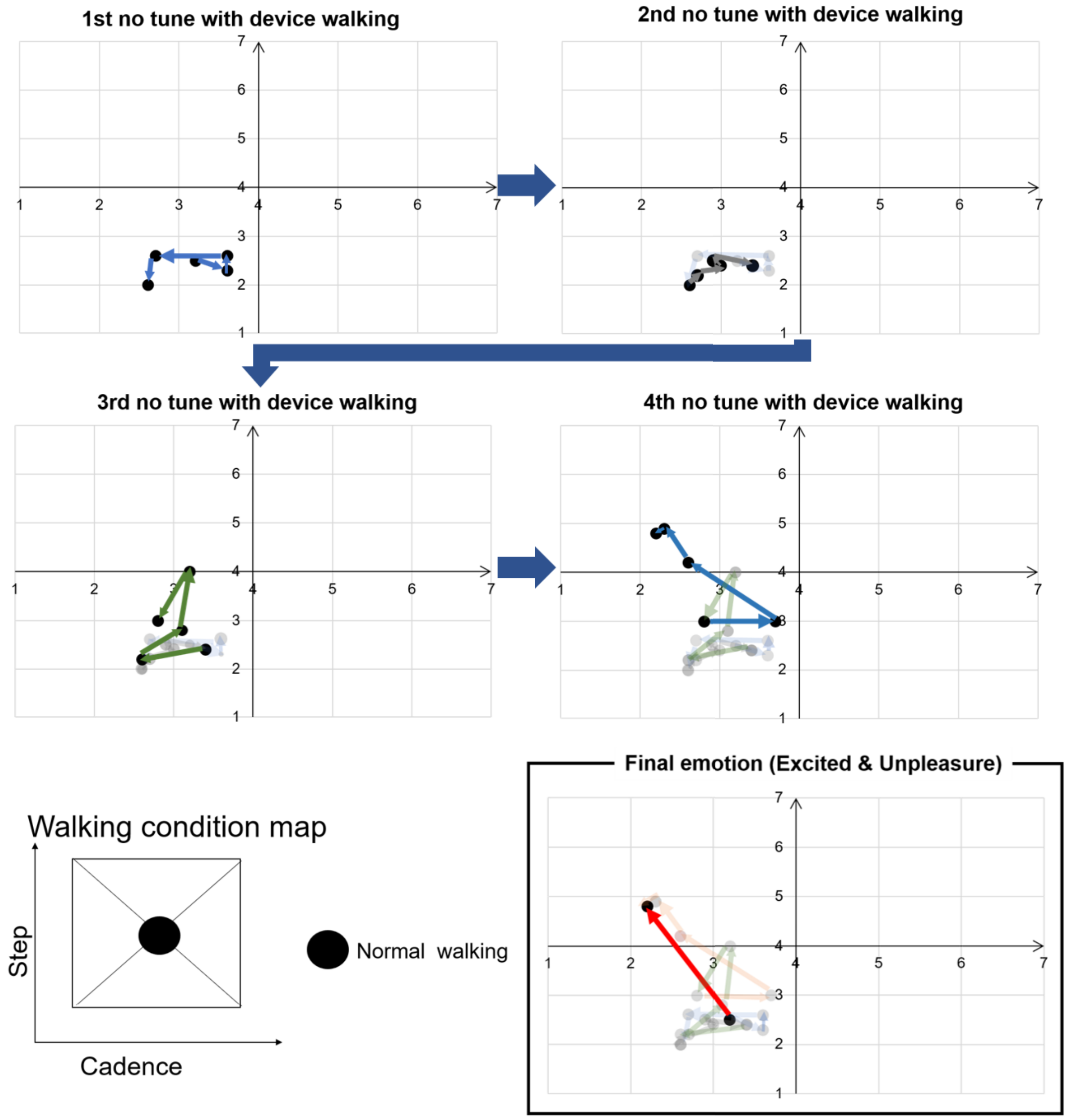


Figure 5.30. Walking with device but without tuning device(subject II).

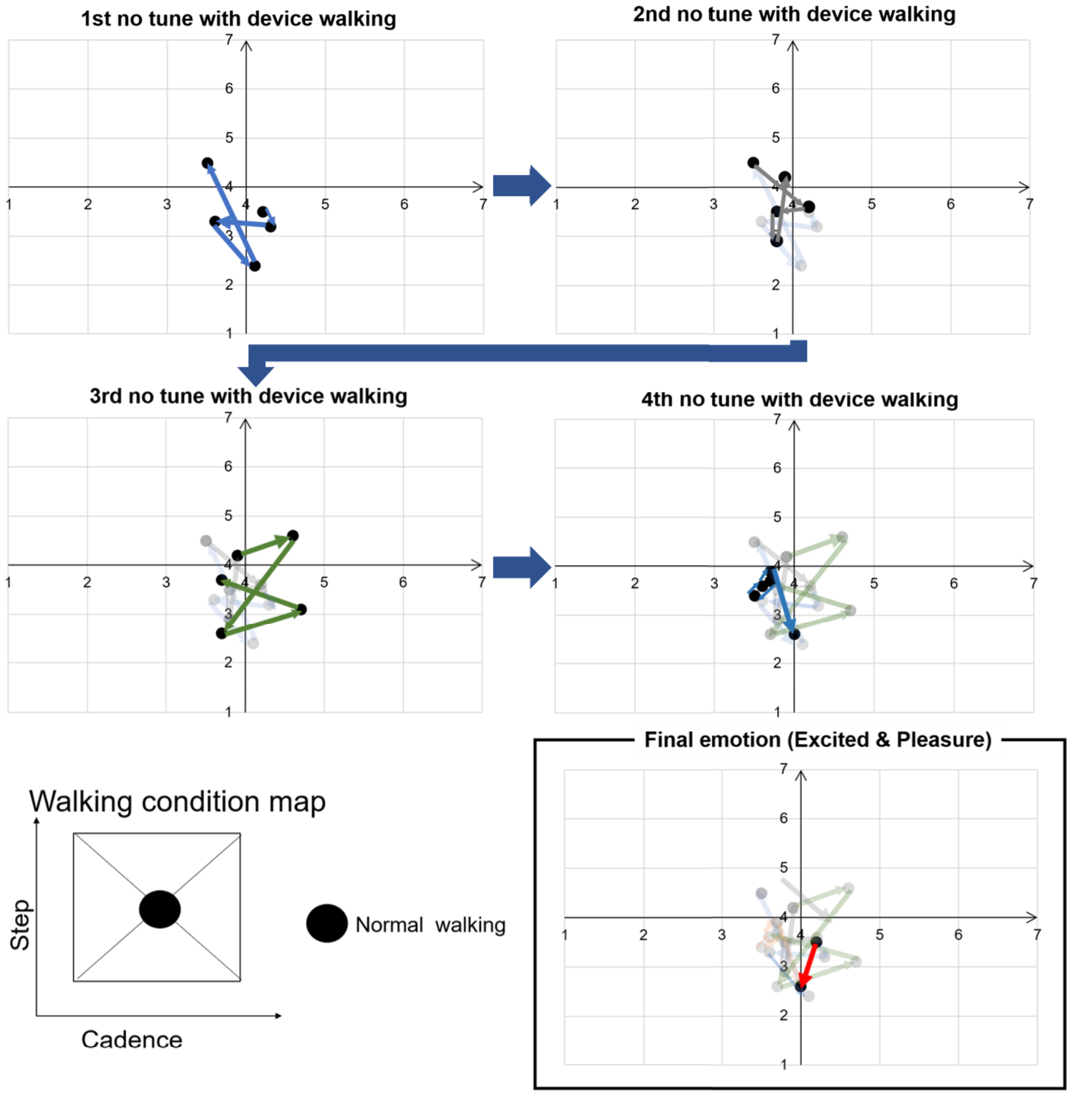


Figure 5.31. Walking with device but without tuning device (subject III).

5.8.11 Results of Walking Without Assistive Device and without Using Strategies

Figure 5.32, 5.33, and 5.34 showed the average emotion response of walking without device (free walking).In this condition, we observed that the final emotion becomes unpleasure and unexcited compared with initial emotion in three subjects. They mentioned that compared with wearing device, the feeling becomes better, but after long time walking, they feel very bored. From their description, we thought that the walking condition should not single, which would not give the effective assistance to the people.

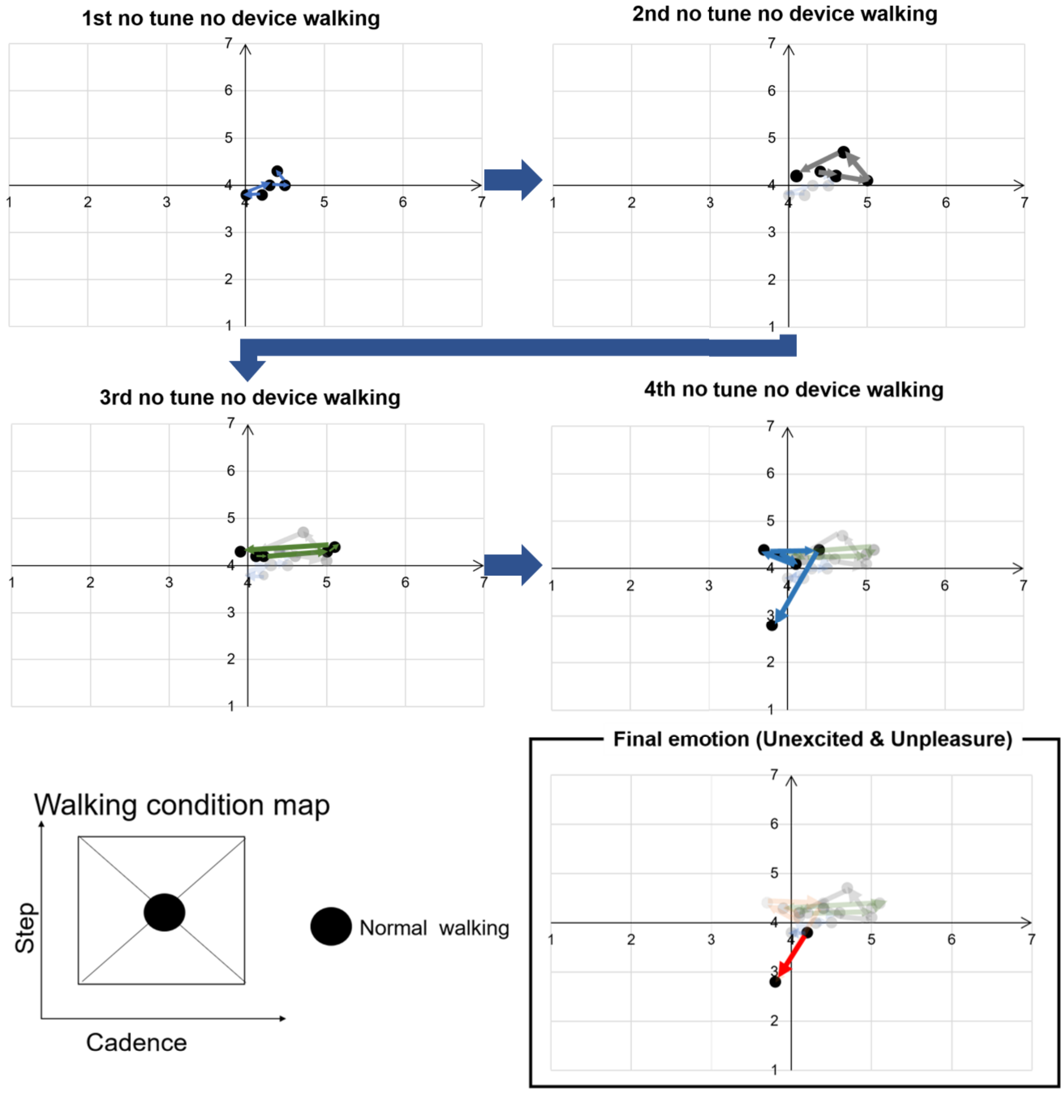


Figure 5.32. Walking without device (subject I).

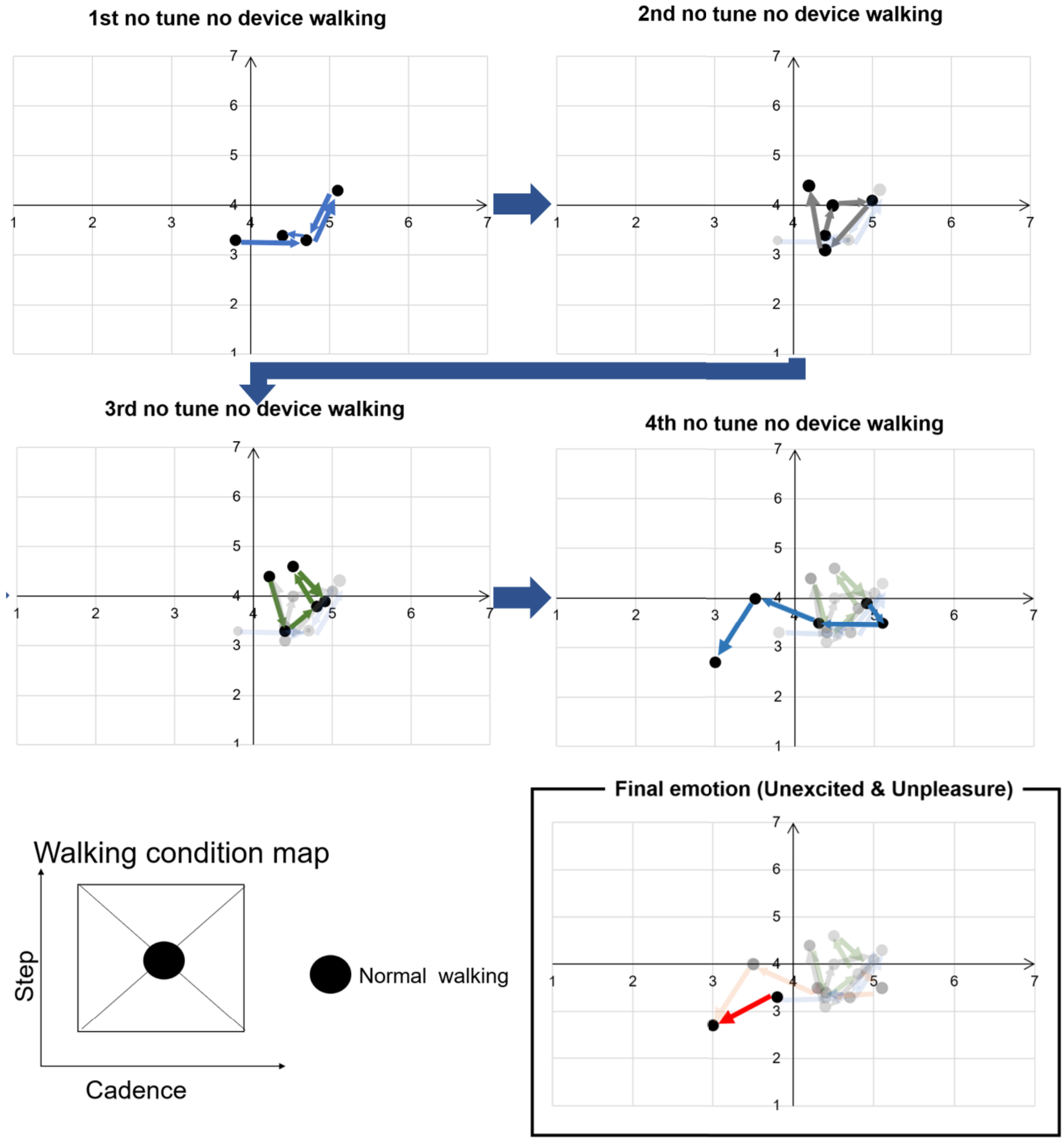


Figure 5.33. Walking without device(subject II).

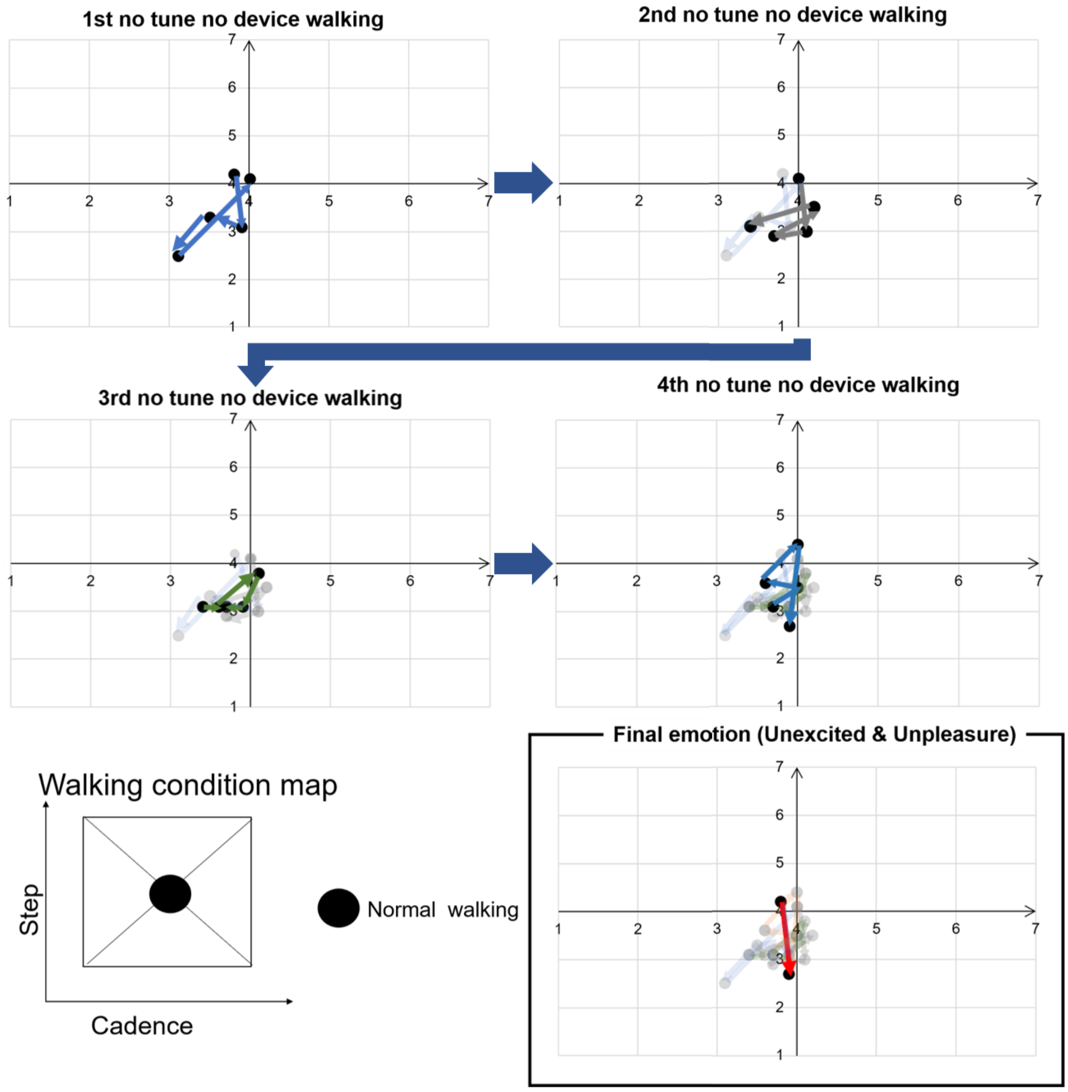


Figure 5.34. Walking without device (subject III).

5.8.12 Evaluation of Emotion- Walking System Applying Walking Strategies

We prepared the walking test which was used to evaluate the effectiveness of walking strategies. We compared the four conditions in the walking test: 1.Walking with device and with tuning method by repeated walking. 2.Walking with device and with tuning method by cycled walking. 3.Walking with device but without tuning method. 4.Walking without device and also without tuning walking condition by strategies.

Figure 5.35 and 5.36 respectively shows each subject's emotion response from initial emotion to final emotion when they walked with device and with tuning method by repeated walking and cycled walking. By averaged three subject results of repeated walking strategy, the pleasure emotion can be increased +8.6[%][point/quest.], and the arousal emotion can be elevated +15.7 [%][point/quest.]. Additionally, the averaged results of cycled walking strategy showed that the pleasure and arousal emotion can elevate 18.1 [%][point/quest.] and 15.2 [%][point/quest.], respectively. These results indicted that the proposed walking strategies could promote the users emotion to the positive states.

When walking with device but without tuning method, the experiment results exhibited that the final pleasure emotion decreased -6.7[%][point/quest.] and the arousal decreased(-9.0 [%][point/quest.]), as shown in Fig.5.37. Furthermore, in third condition, when walking without device and also without tuning walking condition by strategies, we observed that the final emotion becomes unpleasure and unexcited compared with initial emotion (-11.4 [%] and -23.8[%]), as shown in Fig.5.38. From above results, the observation shows that without tuning device would decrease the current pleasure and arousal emotion. Moreover, from the oral description of the subjects, they unanimously believe that under a long-time walking, they feel very bored and don't even want to continue the experiment. Compared to the tuning device depending on the walking strategy, a variety of walking combinations allow them to maintain freshness and challenge while walking. This makes their emotional changes appear more intense and can be promoted to positive emotions.

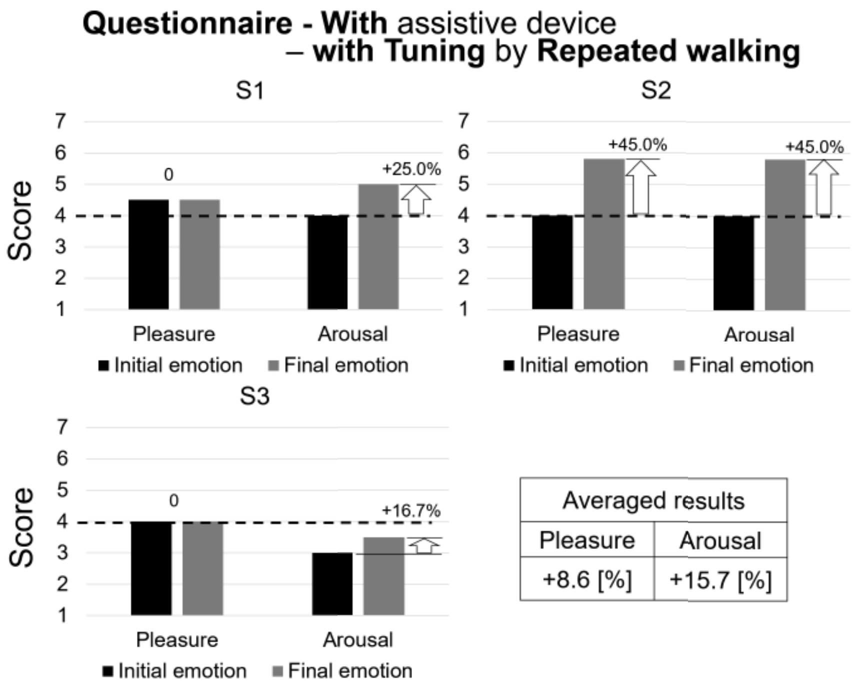


Figure 5.35. Walking with device and with tuning method by repeated walking.

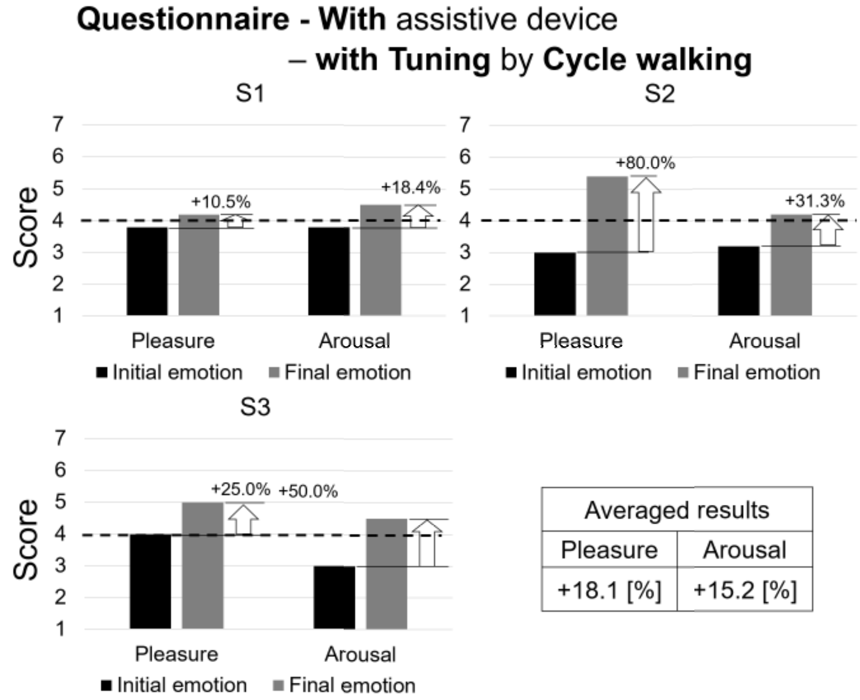


Figure 5.36. Walking with device and with tuning method by cycled walking.

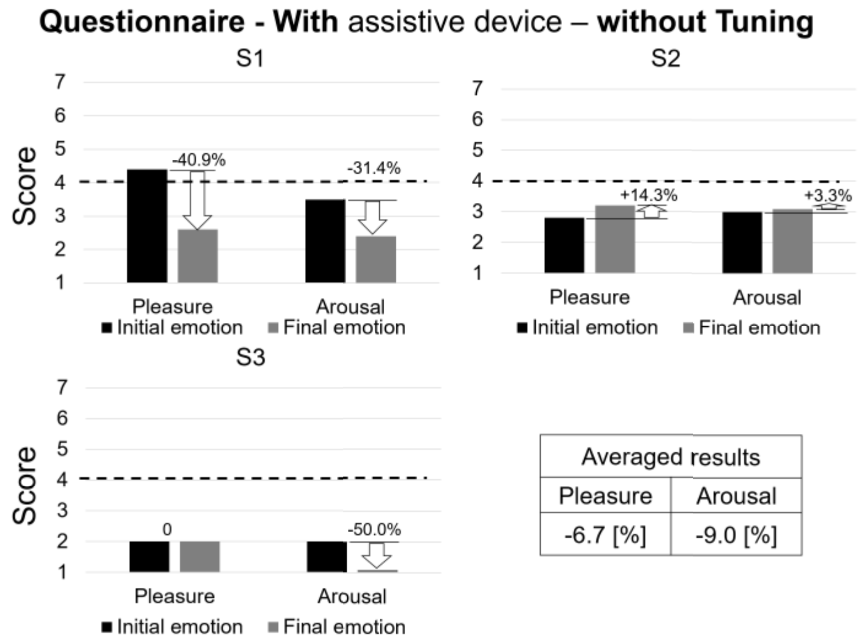


Figure 5.37. walking with device but without tuning method.

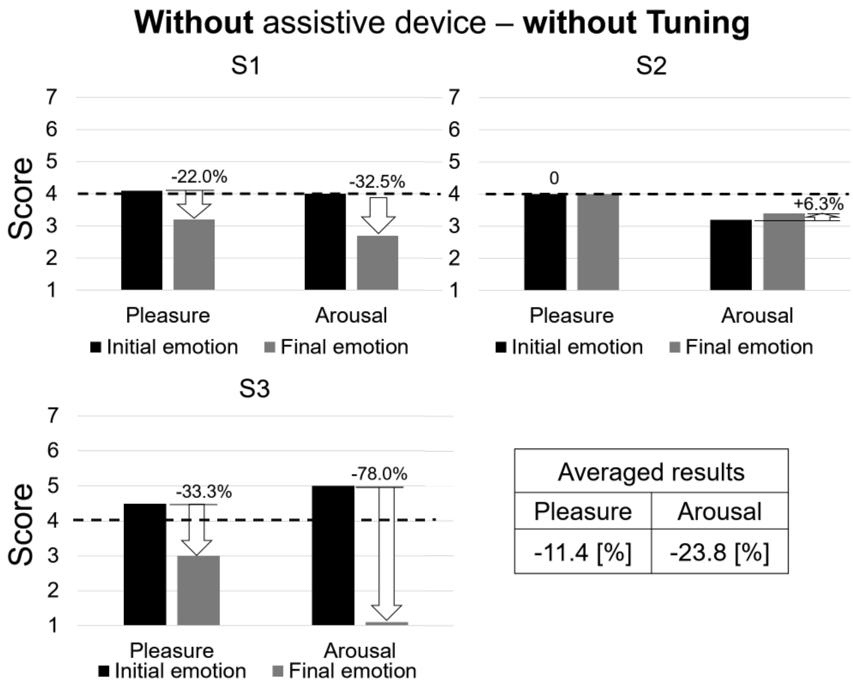
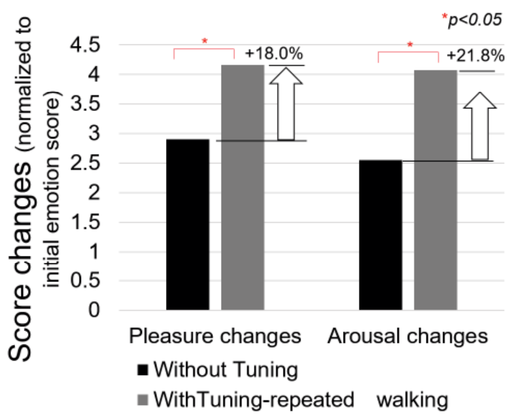


Figure 5.38. Walking without device and also without tuning walking condition by strategies.

To evaluate the effectiveness of the tuning method, we used the one-tail paired t-test to compare a significant change in with and without tuning an assistive walking device (significant level 95%). The data were collected by emotion changes every two minutes, and further normalized to the initial emotion. Figure 5.39 depicted the evaluation of significant in repeated walking strategy. The results indicated that the pleasure changes (normalized to initial emotion point) were elevated significantly (+18.0[%][point/ quest.], $p<0.05$); the arousal changes (normalized to initial emotion point) can be promoted +21.8[%][point/ quest.]($p<0.05$) from initial emotion. For using cycled walking strategy as shown in Fig. 5.40, we observed the pleasure and arousal emotion can significantly be promoted from initial emotion, respectively (+17.6[%][point/ quest.], $p<0.05$ and +15.3[%][point/ quest.], $p<0.05$). As the indicated evaluated results, it illustrated that when users walked with these two walking strategies, their emotion can be significantly promoted to the positive states. To confirm more effectiveness while using this system, we further evaluated the significant in "with device-t - without tuning", as shown in Fig.5.41 and Fig.5.42. These two conditions belong to an independent event, it thus used the independent t-test to evaluate their significance. The findings depicted that when using this device with these using walking strategies, the emotion was significantly promoted and improved, compared with free walking (with using device). The increased percentage of emotion while using repeated and cycled walking are: pleasure (+7.9%) and arousal (+15.3%,p<0.05); pleasure (+7.0%) and arousal (+9.5%), respectively. As indicated comparison, we can prove the effectiveness of this system with the proposed walking strategies. After that, we aims to make this system to being a real application. We thus directly examine this control strategy by using emotion recognition system. Compared to initial emotion and final emotion of the users, averaged results of users' pleasure promoted from 3.1 to 5.5 [point] (+33%), and arousal promoted from 3.3 to 4.2 [point] (+12%), as shown in Fig. 5.43. Through the evaluation of emotion change, we observed this control method can significantly promote and maintain the users' emotion in the positive area. These results illustrated that the users can keep their motivation and obtain the walking assistance synchronously, thus, they can continuously do the exercise for a long time. We also recommend using this proposed approach for clinical treatment.

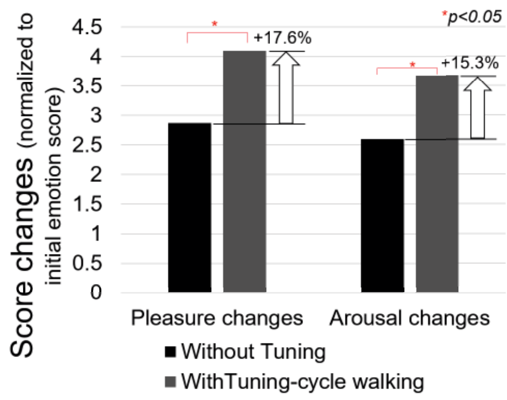
Evaluation of significant in **Repeated walking strategy**



Pleasure changes		
Paired- T-Test		
	With tuning	Without tuning
Mean	4.161265	2.900323
Variance	1.087765	0.410475
Sample	15	15
t value	5.061973	
P value	*8.67E-05	
Critical value	1.76131	

Arousal changes		
Paired- T-Test		
	With tuning	Without tuning
Mean	4.076111	2.550899
Variance	0.943085	0.349196
Sample	15	15
t value	4.883394	
P value	*0.000121	
Critical value	1.76131	

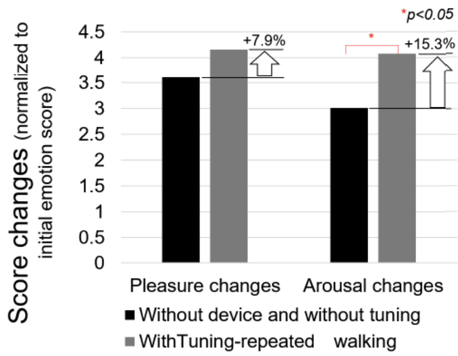
Figure 5.39. Evaluation of significant in Repeated walking strategy in comparison to with tuning and without tuning.



Pleasure changes		
Paired- T-Test		
	With tuning	Without tuning
Mean	4.099211	2.870354
Variance	1.596495	0.390046
Sample	12	12
t value	4.115855	
P value	*0.000856	
Critical value	1.795885	

Arousal changes		
Paired- T-Test		
	With tuning	Without tuning
Mean	3.674068	2.601157
Variance	0.557167	0.363629
Sample	12	12
t value	3.489341	
P value	*0.002532	
Critical value	1.795885	

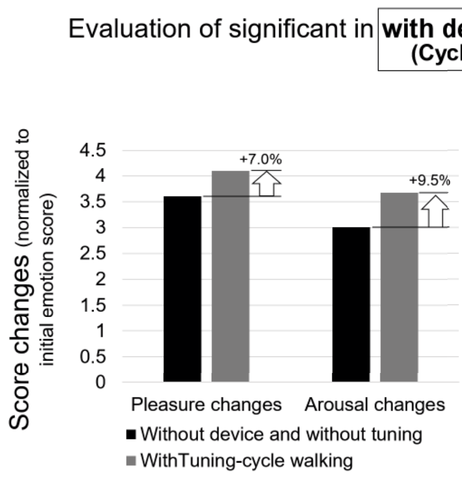
Figure 5.40. Evaluation of significant in cycled walking strategy in comparison to with tuning and without tuning.



Pleasure changes		
Independent Sample T-Test		
	With device-tuning	Without device-Without tuning
Mean	4.161265	3.607751
Variance	1.087765	0.32149
Sample	15	12
t value	1.649598	
P value	0.055768	
Critical value	1.708141	

Arousal changes		
Independent Sample T-Test		
	With device-tuning	Without device-Without tuning
Mean	4.076111	3.008063
Variance	0.943085	1.337907
Sample	15	12
t value	2.609495	
P value	*0.007547	
Critical value	1.708141	

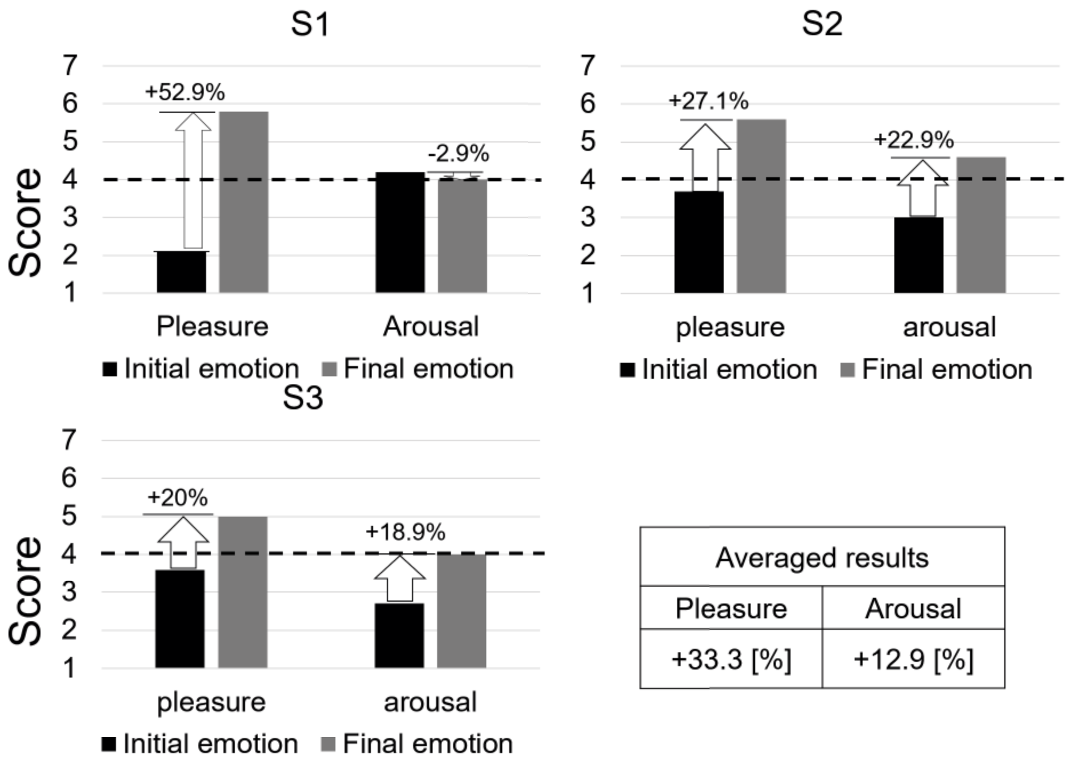
Figure 5.41. Evaluation of significant in repeated walking strategy in comparison to with tuning and without tuning.



Pleasure changes		
Independent Sample T-Test		
	With device-tuning	Without device-Without tuning
Mean	4.099210526	3.607751
Variance	1.596494762	0.32149
Sample	12	12
t value	1.229294983	
P value	0.115973723	
Critical value	1.717144374	

Arousal changes		
Independent Sample T-Test		
	With device-tuning	Without device-Without tuning
Mean	3.674067982	3.008063
Variance	0.557166971	1.337907
Sample	12	12
t value	1.675928034	
P value	0.05395399	
Critical value	1.717144374	

Figure 5.42. Evaluation of significant in cycled walking strategy in comparison to with tuning and without tuning.



Averaged results	
Pleasure	Arousal
+33.3 [%]	+12.9 [%]

Figure 5.43. Results of applying control strategy into system.

5.9 Discussion

As the indicated results above, we understood the emotion was able to be stimulated by the different walking conditions. Contrarily, the walking conditions also were able to be activated by emotion. PWR is suitable to analyze the emotion-walking relationship because it can prevent excessive emotion happen from excessive walking. Also, for the patient, generally, they have totally different gait patterns to healthy people; therefore, the proposed PWR can offer to the medical staff to understand the patients' walking limitations and guide patients to walk comfortably. We finally sorted out the results: when people walked on the conditions of the "slow" and "long step length-low cadence", we found that could calm down the affective of people. When people walked at the "fast", the emotions could be promoted; whereby, the excited with pleasure emotion was evoked. When people did the "short step length-high cadence" walking, the results revealed that the people felt unhappy.

Emotion recognition system is a useful tool for medical staff to understand the patients' emotions. We had verified our developed recognition system which could show the consistent tendency with questionnaire responses (accuracy of 75[%]). Whereby, we believe that the system has a high possibility to use in the real world as a valuable application for serving rehabilitation.

The walking strategies for stimulated to positive emotion was proposed. The findings showed that the people emotion could be influenced by repeated walking and cycled walking. In the 2D emotion map, the first and fourth quadrant means that people feel contented, relax, and pleasure in their affective perception. These two quadrants are very important to the patients or elderly during rehabilitation or exercise. Therefore, if the patients can maintain their emotions in that two quadrants, it can valid keep the motivation for continuing rehabilitation. Furthermore, through repeated walking and cycled walking, the emotion can be validly promoted to contented, relax, and pleasure perception, which leads to people to maintain positive emotion. Comparison of two strategies, the repeatedly walking showed the better effects than cycled walking.

Through experiment of using emotion to control walking, it proved that the emotion was gradually promoted and maintained to the positive state (in Section 5.6). The findings also verified that the subject can be changed in gait by the drive of the device, and the subject does not have to walk in a single walking condition; instead, a variety of repeatedly walking combinations are used to maintain the freshness of the subjects during the experiment. They were thus gradually elevated the sense of challenge and satisfied the sense of walking with the device, and further, achieve the promotion of positive emotion. For real applications, for the elderly or the patient's daily goals during exercise or rehabilitation (for instance, completing 1 km of walking), they can be adjusted the walking condition according to emotion changes. Then through repeated walking and cycle strategies, keeping positive emotions all the time finally achieves goals, at the same time, they will also acquire the feeling of self-satisfaction and self-fulfillment during exercise or rehabilitation.

5.10 Conclusions

To integrate the emotion and walking, the 2D walking condition map and 2D emotion map were firstly studied for exploring the emotion-walking relationship. By observing the walking vector and the emotion vector, the results proved walking changes can determine the direction of emotion changes. The results showed that when people walked along with a personal preferred walking ratio (PPWR) and a vertical of PPWR, emotions separately become a positive and a negative state. The feasibility of the emotion system using in walking was proved because it showed a consistent with questionnaire (quest.) results (accuracy of 75% [system/quest.]). A hybrid system using emotion- walking interaction was developed. To raise the assistive effect, the repeated and cycled walking were proposed as strategies to promote the emotion. By questionnaire results (total point of 7), when walking with device but without tuning, pleasure, arousal emotion: 2.9, 2.6 [point]. When walking with device and with repeated tuning, pleasure, arousal: 4.2, 4.1 [point]; besides, when using cycle tuning, pleasure, arousal: 4.1, 3.7 [point]. Compared to with tuning and without tuning while using device, the results proved when using repeated walking: users' pleasure promoted from 2.9 to 4.2 [point] (+18%), and arousal promoted from 2.6 to 4.1 [point] (+22%). When using cycled walking, users' pleasure promoted from 2.9 to 4.1 [point] (+18%), and arousal promoted from 2.6 to 3.7 [point] (+15%). Then, when walking without device, it induced the pleasure reduced from 4.2 to 3.4 [point] (-11%) and arousal reduced from 4.1 to 2.4 [point] (-24%). Finally, to make this system to be used as a real application, we thus directly examine this control strategy by using emotion recognition system. Compared to initial emotion and final emotion of the users, averaged results of users' pleasure promoted from 3.1 to 5.5 [point] (+33%), and arousal promoted from 3.3 to 4.2 [point] (+12%). The results proved the proposed system and strategy can promote and maintain the positive emotion of users further lead to achieve highest dual assistance of walking and emotion during the exercise.

Chapter 6

Conclusions

6.1 Conclusions

Owing to the aging population have been increasing, the issues of the prevention of a stroke are considerably concerned in the elderly. The observation of extended issues in the aging showed that physical weakness and mind state of the elderly led to a stroke. To resolve these problems, long-term properly exercise has been proposed to be a good way. However, how to effectively "do exercise," "maintain the elderly motivation," which are the most important issues to be studied. The purpose of this dissertation is to conduct a feasible study on the development of a hybrid system that integrates emotion evaluation and walking assistance for providing the synchronous promotion at physical aspect and mental aspect further maintaining the motivation during exercise. To construct a hybrid system, this study separately studied walking assistance, emotion evaluation, and integration of emotion and walking. After that, the methods for "how to promote and maintain the positive emotion" is also studied. Finally, a hybrid system was constructed. By using this system, the elderly can synchronously acquire gait improvement and gain pleasure emotions for maintaining motivation in long-term exercise. They can attain self-exercise without other people help to regain self-confidence.

In chapter 3, to offer the best walking assistance for elderly, the device does not need to much power; and, elderly only need to be informed the motion and timing during walking; therefore, they can achieve the promotion of exercise. Thus, the assistive device should be designed as small as possible. From the existed proposed device, it still not small enough due to high power motor use. To reach effectively assistance with a very compact design, a new device is proposed. This device uses a compact geared servo motor to generate enough power and offer a very compact size for the users. Currently, to make a very compact motor, the safety factor would be designed to close to 1. However, the device easily encounters unexpected overloads that lead to a gear broken in the motor. For the prevention of breakage, a new compact torque limiter was designed in a gear of motor, which maintains the same size and weight as the original gear. Thus, the users can be reached the minimum burden while using this device. Furthermore, through experiment verification, the compact torque limiter shows an excellent service life (can use at least 300 times (1 exercise/ day for 30 min encounters 1 accident. It can be used for 10 months.)). After that, this walking device with a compact torque limiter has been verified. The results proved when the device was used, it can significantly improve the dorsiflexion motion from 15 to 28 [deg] (+46%), the kicking timing from 75% to 70% (-7%), and the step length from 0.68 to 0.75 [m] (+9%). These results represents this device can offer walking assistance effectively, further achieve the promotion of exercise. Finally, from the existed proposed device problems, a small and lightweight assistive device with a compact torque limiter is proposed to effectively resolve the problems for the elderly to gain the promotion of exercise.

In chapter 4, to study the emotional state of people, the great way is to use the physiological signals to be analyzed further respond the human emotion. From the existed proposed emotion recognition systems had problems of only a few states prediction and using outer physiological signals (such as voice and facial motion) t

(DNN) models as the classifier being an emotion recognition system, which can recognize the nine states of human emotion. Separately each valence and arousal state can be divided into three groups using our proposed DNN and achieve a good classification accuracy, for discriminating the valence state (up to 79% (403 data/ 510 total data)) and the arousal states (81% (431 data/ 510 total data)). This DNN validated its superior accuracy in comparison with other algorithms (SVM, Naïve Bayes, and K-means). Additionally, through a verification experiment, this system shows good performance while using in the real situation (t / questionnaire]). Finally, the proposed emotion recognition system resolves the existed studies' problems for identifying multiple emotion states and responding to real emotion without fake.

In chapter 5, to achieve the final goal of integrating mental and physical conditions, it is necessary to propose the hybrid system for the elderly synchronously gain dual assistance further maintaining motivation during exercise. From the previous research, the existed device could not determine the people's emotions state and thus it is very hard to maintain motivation. To connect the emotion and walking, the 2D walking condition map and 2D emotion map were firstly studied for exploring the emotion-walking relationship. By observing the walking vector and the emotion vector, the results proved walking changes can determine the direction of emotion changes. The results showed that when people walked along with a personal preferred walking ratio (PPWR) and a vertical of PPWR, emotions separately become a positive and a negative state. After that, how to promote the user emotion to the positive area is a key factor to maintain motivation. Considering the practical applicability of this hybrid system, it is difficult to use other devices to stimulate the emotion of the users. Thus, the repeated and cycled walking were proposed as strategies to promote the emotion. By questionnaire results (total point of 7), when walking with device but without tuning, pleasure, arousal emotion: 2.9, 2.6 [point]. When walking with device and with repeated tuning, pleasure, arousal: 4.2, 4.1 [point]; besides, when using cycle tuning, pleasure, arousal: 4.1, 3.7 [point]. Compared to with tuning and without tuning while using device, the results proved when using repeated walking: users' pleasure promoted from 2.9 to 4.2 [point] (+18%), and arousal promoted from 2.6 to 4.1 [point] (+22%). When using cycled walking, users' pleasure promoted from 2.9 to 4.1 [point] (+18%), and arousal promoted from 2.6 to 3.7 [point] (+15%). Then, when walking without device, it induced the pleasure reduced from 4.2 to 3.4 [point] (-11%) and arousal reduced from 4.1 to 2.4 [point] (-24%). After that, a hybrid system of walking assistance considering emotion evaluation is proposed. Furthermore, a control strategy applying in this hybrid system aims to promote and maintain the emotion in the positive area (at the 1st and 4 the quadrant of emotion map) was proposed. Through using this control strategy with device, compared to initial emotion and final emotion of the users, averaged results of users' pleasure promoted from 3.1 to 5.5 [point] (+33%), and arousal promoted from 3.3 to 4.2 [point] (+12%). When using this system, when the emotion change (obtained by emotion recognition system), the system can give the target walking condition for tuning the angle amplitude and walking cycle of the compact assistive device; thus, the users can satisfy their emotions and walk at the same time during the exercise. Finally, the proposed system resolves the problems of the previous studies (they cannot maintain motivation). By using this system, the elderly can gain a high sense of achievement further keep motivation and promote confidence in real life without other people's help.

6.2 Future work

In the future, the different conditions of the rehabilitation need to be concerned. When the users feel positive emotion for a long time, however, the body condition is not suitable for continuing performing the rehabilitation. At that time, patients should stop rehabilitation. Thus, body fatigue is also an important issue that has to be concerned. For integrating the body condition, emotion and walking, our system can provide more deeply assistance and validly application. Additionally, the proposed system should be completed the auto-t -
tion change. Furthermore, in response to the growth of the IoT (Internet of Things), the further study will focus on cloud computing in the future, users can upload and download their personal physiological information, such as personal gait, emotional state, etc. in various places. Thus, users can apply this hybrid assistance system at home to complete the self-rehabilitation, which can resolve the problems of insufficient medical staff.

Acknowledgements

Deeply gratitude goes first to Professor Tanaka, who expertly guided and taught in my whole doctoral course. Owing to his great assistance, the dissertation could be completed. His rigorous but optimistic spirit makes me earn much knowledge. In the past three years, research, experience, and etiquette have firmly affected my mind. These things are quite precious to me. Thank you very much.

Sincerely appreciated the instruction of the Production filed Professor. Especially, I would like to thank Prof. Lee, Prof. Tateno, Prof. Simuzu, Prof. Ogai, and Prof. Miyake. Owing to your instruction and advice in three years, I could complete this research and doctoral thesis. Thank you very much.

Specially thanks to the Saitama University Prof. Watanuki and Prof. Muramatsu, Kondo Kagaku co.,ltd. President Kondo, Saitama University's Mr. Tanaka, Mr. Osawa, Waseda University's Mr. Nagayoshi, Ms. Guan, Mr. Wu, Mr. Osawa, and Mr. Yang. Due to yours assistance, this research could be completed.

Especially to thank Mr. Liao and Mr. Yang, you guys have accompanied me to beat any challenge at every period of the past three years. You guys also have given constantly encourage to me, thanks a lot.

Thanks for all the lab members. Especially for the member of ZHUANG team, sincerely appreciated.

Finally, much appreciated everyone who has given me a lot of assistance.

Reference

[1] Zarb, G. and Oliver, M., Ageing with a disability. W ll these years? London: University of Greenwich, available from <h /disability-studies.leeds.ac.u - - - .pdf>, (accessed on 20 January 2020).

[2] Calasanti, T. and Slevin, K. (Eds.). Age matters: Realigning feminist thinking. New York: Routledge (2012).

[3] Ja ., WHO on Aging Populations: Think Investment, Not Cost, Agewyz, available from <h .com/who-on-aging-populations-think-investment-not-cost/>, (accessed on 20 January 2020).

[4] Population ages 65 and above (% of Total Population), World Bank Staff Estimates Based on Age/Sex Distributions of United Nations Population Division's World Population Prospects: 2019 Revision, The Word Bank (online), available from < https://reurl.cc/D13QpR>, (accessed on 20 January 2020).

[5] Hayution, A. M., Graying of the Global Population, Public Policy & Aging Report, Vol. 7, No. 4 (2012), pp. 12-17.

[6] Nakayama, H., Jørgensen, H. S., Raaschou, H. O. and Olsen, T. S., The influence of age on stroke outcome. The Copenhagen Stroke Study., Stroke, Vol.25, No.4 (1994), pp. 808–813.

[7] Lindley, R. I., Stroke prevention in the very elderly, Stroke, Vol.49, No.3 (2018), pp. 796-802.

[8] Wolfe, C. D. A., The impact of stroke, British Medical Bulletin, Vol. 56, Issue 2 (2000), Pages 275–286.

[9] K . I., Palazzolo, J. J., Dipietro, L., Ferraro, M., Krol, J., Rannekleiv, K., Volpe, B.T. a ., Rehabilitation robotics: performance-based progressive robot-assisted therapy, Autonomous Robots, Vol.15, No.1, pp. 7–20.

[10] Colombo, R., Pisano, F., Micera, S., Mazzone, A., Delconte, C., Carrozza, M. C., Dario, P. and Minuco, G., Assessing mechanisms of recovery during robot-aided neurorehabilitation of the upper limb, Neurorehabilitation and Neural Repair, Vol. 22 No. 1, pp. 50–63.

[11] Jing, D. W. and Zhang J. C., Research and development of rehabilitation engineering, Modern rehabilitation, Vol. 4, No. 5 (2000).

[12] Koh, C., Hoffmann, T., Bennett, S. and McKenna, K., Management of patients with cognitive impairment after stroke: A survey of Australian occupational therapists. Australian Occupational Therapy Journal, Vol. 56 (2009), pp. 324-331.

[13] Riener, R., Lünenburger, L. and Colombo, G., Human-centered robotics applied to gait training and assessment, Journal of Rehabilitation Research & Development, Vol. 43, No. 5 (2006), pp. 679–694.

[14] Schmitt, K. U., Niederer, P. F., Cronin, D. S., Muser, M. H. and Walz, F., Injuries of the Pelvis and the Lower Extremities, Trauma Biomechanics: An Introduction to Injury Biomechanics (2014), pp. 153-178, Springer Berlin Heidelberg.

[15] A graphic showing Lower Extremity Muscles | school | Lower limb muscles, Lower leg muscles, Peroneus longus, Pinterest, available from < h /w).

[16] Moromizato, K., Kimura, R., Fukase, H., Yamaguchi, K. and Ishid, H., Whole-body patterns of the range of joint motion in young adults: masculine type and feminine type, Journal of Physiological Anthropology, Vol. 35, No. 23 (2016).

[17] Stöckel, T., Jacksteit, R., Behrens, M., Skripitz, R., Bader, R. and Mau-Moeller, A., The mental representation of the human gait in young and older adults, Front Psychol, Vol.6 (2015), pp. 943.

[18] Chiu, S. L., Chang, C. C., Dennerlein, J. T. a - - (2015), pp. 152-157.

[19] Prince, F., Corriveau, H., Hébert, R. and Winter, D. A., Gait in the elderly, Gait & Posture, Vol. 5,

Issue 2 (1997), pp. 128-135.

[20] Sebastiaan, D. , Lenka, R. and Katrien, K., The Role of Inflammation in Age-Related Sarcopenia, Frontiers in Physiology, Vol. 8 (2017), pp. 1045.

[21] Mechling, H. and Netz, Y., Aging and inactivity—capitalizing on the protective effect of planned physical activity in old age, Eur Rev Aging Phys Act, Vol. 6 (2009), pp. 89–97.

[22] Tanaka, E., Suzuki, T., Saegusa, S. and Yuge, L., Walking assistance apparatus able to select the control method according to the purpose of the user, World Automation Congress, (2014), pp.537–542.

[23] Rejeski, W. J. and Brawley, L. R., Functional health: innovations in research on physical activity with older adults, Med Sci Sports Exerc, Vol. 38 (2006), pp. 93–99.

[24] Can muscle decline due to aging be suppressed or even stopped, In lable from < https://www.innovationtoronto.com/2019/06/can-muscle-decline-due-to-aging-be-suppressed-or- even-stopped/>, (accessed on 20 January 2020).

[25] Wilk, R. and Johnson, M. J., Usability feedback of patients and therapists on a conceptual mobile service robot for inpatient and home-based stroke rehabili IEEE RAS/EMBS In -

[26] Bogue, R., Exoskeletons and robotic prosthetics: a review of recent developments, Ind Robot, Vol.36, No.5 (2009), pp.421–427.

[27] Sankai, Y., HAL: Hybrid assistive li l A le, Vol.66 (2010), pp. 25-34.

[28] Buesing, C., Fisch, G., O'Donnell, M., Shahidi, I., Thomas, L., Mummidisetty, C. K., Williams, K. J., Takahashi, H., Rymer, W. Z. and Jayaraman, A., Effects of a wearable exoskeleton stride management assist system (SMA®) on spatiotemporal gait characteristics in individuals after stroke: a randomized controlled trial, Journal of Neuro Engineering and Rehabilitation, Vol.12, No.1 (2015), pp. 69.

[29] Esquenazi, A., Talaty, M., Packel, A. and Saulino, M., The ReWalk powered exoskeleton to restore ambulatory function to individuals with thoracic-level motor-complete spinal cord injury, Am J Phys Med Rehabil, Vol.91, No.11 (2012), pp. 911-21.

[30] Zhang, X. and Hashimoto M., Synchronization-based trajectory generation method for a robotic suit using neural oscillators for hip joint support in walking, Vol.22, No.1 (2015), pp. 33-44.

[31] Hwang, S., Kim, J., Yi, J.,Tae, K., Ryu, K. and Kim, Y., Development of an active ankle foot orthosis for the prevention of foot drop and toe drag, ICBPE 2006 - Proceedings of the 2006 In (2007), pp. 418-423.

[32] Takaiwa, M. and Ysusda, N., Pneumatic walking support shoes using wearer's weight, The Proceedings of the Machine Design and Tribology Division meeting in JSME (2018), 2B3-2.

[33] Tanaka, E., Muramatsu, K., Watanuki, K., Saegusa, S., and Yuge, L., Development of a Walking Assistance Apparatus for Gait Training and Promotion of Exercise, 2016 IEEE In ICRA 2016), (2016), pp. 3711-3716.

[34] Miyake, Y., Interpersonal Synchronization of Body Motion and the Walk-Mate Walking Support Robot IEEE Transactions on robotics, Vol. 25, No. 3 (2009), pp. 638-644.

[35] Fey, N. P., Klute, G. K., and Neptune, R. R, Optimization of Prosthetic Foot Stiffness to Reduce Metabolic Cost and Intact Knee Loading During Below-Knee Amputee Walking: A Theoretical Study, ASME. J Biomech Eng, Vol. 134, No. 11 (2012).

[36] Mooney, L. M., Rouse, E. J. and Herr H. M., Autonomous exoskeleton reduces metabolic cost of walking, 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (2014), pp. 3065-3068.

[37] Malcolm P., Derave W., Galle S., Clercq D. D., A Simple Exoskeleton That Assists Plantarflexion Can Reduce the Metabolic Cost of Human Walking, Vol. 8, Issue 2 (2013).

[38] Galle, S., Malcolm P., Collins, S. H. and Clercq D. D., Reducing the metabolic cost of walking with an ankle exoskeleton: interaction between actuation timing and power, J Neuroeng Rehabil, Vol. 14, Issue 1 (2017), pp. 35.

[39] Sano, A., ACSIV - Issue Supplement (2015), pp. S310.

[40] Collins, S. H., Wiggin, M. B. and Sawicki, G. S., Reducing the energy cost of human walking using an unpowered exoskeleton, Nature, Vol. 522, No. 7555 (2015), pp. 212-5.

[41] Galle, S., Malcolm, P., Derave, W. and Clercq D. D., Uphill walking with a simple exoskeleton: Plantarflexion assistance leads to proximal adaptations, Gait & Posture, Vol.41, Issue 1 (2015), pp. 246-251.

[42] Mooney, L. M., Rouse, E. J. and Herr H. M., Autonomous exoskeleton reduces metabolic cost of human walking during load carriage. Mooney et al. Journal of Neuro Engineering and Rehabilitation, Vol. 11, No. 80 (2014).

[43] Bionic boot new extreme sport/ fitness device, bionic boot, available from < h /w (accessed on 20 January 2020).

[44] Louis N., A., Jaehyun, B., Kathleen, O., Stefano M. M., D. R., Kathryn, H., Lizeth H., S., Pawel, K., Stephen, A., Kenneth G., H., Terry D. E. and Conor J. W., A soft robotic exosuit improves walking in patients after stroke, Science Translational Medicine, Vol. 9, Issue 400 (2017).

[45] van Dijk, W. and der Kooij, H. V., XPED2: A Passive Exoskeleton with Artificial Tendons, IEEE Robot. Autom. Mag., Vol. 21, No. 4 (2014), pp. 56–61.

[46] Adolphs R., Damasio H., Tranel D. and Damasio A. R., Cortical Systems for the Recognition of Emotion in Facial Expressions, Journal of Neuroscience, Vol. 16, Issue 23 (1996), pp. 7678-7687.

[47] Picard N. and Strick P. L., Imaging the premotor areas, Current Opinion in Neurobiology, Vol. 11, Issue 6 (2001), pp. 663-672.

[48] Andreassi, J. L., Psychophysiology: Human behavior and physiological response (4th ed.) (2000), Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

[49] Tanaka, E., Muramatsu, K., Osawa, Y., Watanuki, K., Saegusa, S., Yuge, L., Development of a walking assistance apparatus for promotion of exercise, The 4th International Conference on Design Engineering and Science (ICDES2017), (2017), Paper No. 223.

[50] Agrafioti, F., Hatzinakos, D., Anderson, A. K., ECG pattern analysis for emotion detection. IEEE Transactions on Affective Computing, Vol. 3, Issue 1 (2012), pp. 102–115.

[51] Künecke, J., Hildebrandt, A., Recio, G., Sommer, W. and Wilhelm, O., Facial EMG responses to emotional expressions are related to emotion perception abili l. 9, Issue 1(2014), e84053.

[52] Nakamura, R., Saito, H. and Nagasaki, H., Fundamental Kinematics (2003), pp. 334-335, Ishiyaku publishers Inc, 6th Edition. (In Japanese).

[53] Mehmood, M. R., Du, R. and Lee, H. J., Optimal feature selection and deep learning ensembles method for emotion recognition from human brain EEG sensors. IEEE Access, Vol. 5 (2017), pp. 14797-14806.

[54] Lin, Y., Wang, C., Jung, T., Wu, T., Jeng, S., Duann, J. and Chen, J., EEG-Based emotion recognition in music listening. IEEE Transactions on Biomedical Engineering, Vol. 57, Issue 7 (2010), pp. 1798-1806.

[55] Tripathi, S., Acharya, S., Sharma, R. D., Mittal, S. and Bhattacharya, S., Using Deep and Convolutional Neural Networks for Accurate Emotion Classification on DEAP Dataset, Proceedings of the Twenty-Ninth AAAI Conference on Innovative Applications, Proceedings of the Twenty-Ninth AAAI Conference on Innovative Applications (IAAI-17) (2017), pp. 4746-4752.

[56] Li, L. and Chen, J. H., Emotion Recognition Using Physiological Signals from Multiple Subjects, Intelligent Information Hiding and Multimedia (2006), pp. 355-358.

[57] Gouizi, K., Reguig, F. B. and Maaoui, C., Analysis physiological signals for emotion recognition, In (2011), pp. 147-150.

[58] Basu, S., Emotion recognition based on physiological signals using valence arousal model, Third In Image Information Processing (ICIIP) (2015), pp. 50-55.

[59] Kim, J. and Andre, E., Emotion recognition based on physiological changes in music listening, IEEE Transactions on Pattern Analysis and Machine Intelligence (2008), Vol. 30, No. 12, pp. 2067-2083.

[60] Maaoui, C., Pruski A. and Abdat F., Emotion recognition for human-machine communication, IEEE/RSJ In Intelligent Robots and Systems (2008), pp. 1210-1215.

[61] Mcleod, S., Maslow's Hierarchy of Needs, Simply Psychology, available from <h /w >, (accessed on 20 January 2020).

[62] Zalenski, R. J. and Raspa, R., Maslow's hierarchy of needs: a framework for achieving human potential in hospice, Journal Palliative Medicine, Vol. 9 (2006), pp. 1120-1127.

[63] Herr, H., Exoskeletons and orthoses: classification, design challenges and future directions, Journal of NeuroEngineering and Rehabilitation, Vol. 6, (2009), p. 21.

[64] Michael, K.M. and Shaughnessy, M., Stroke Prevention and Management in Older Adults, Vol. 21, No. 55, (2006), pp S21-S26

[65] Lindley, R. I., Stroke Prevention in the Very Elderly l.49, No.3(2018), pp. 796-802.

[66] Sawicki, G. S., and Ferris, D. P., Mechanics and energetics of level walking with powered ankle exoskeletons, The Journal of Experimental Biology, Vol. 211, (2008), pp. 1402-1413.

[67] Lauzier, N. and Gosselin, C., 3-DOF Cartesian Force Limiting Device Based on the Delta architecture for safe physical h - IEEE In l Conference on Robotics and Automation (ICRA2010), (2010), pp. 3420-3425.

[68] Park, J. J. and Song, J. B. Safe joint mechanism using incli link with springs for collision safety and positioning accuracy of a robot arm, 2010 IEEE In (ICRA2010), (2010), pp. 813-818.

[69] Atallah, K., Calverley, S. D. and Howe, D., A Brushless Permanent Magnet Motor With In - IEEE Transactions on Magnetics, Vol. 43, No. 6, (2007), pp. 2498-2500.

[70] Fukui W., Kobayashi, F., Kojima, F., Nakamoto, H., Maeda, T., Imamura, N., Sasabe K. and Shirasawa H., Development of multi-fingered universal robot hand with torque limiter mechanism, 35th Annual Conference of IEEE Industrial Electronics, (2009) pp. 2205-2210.

[71] Guo, X., Zhang, W., Liu, H., Yu, Z., Zhang, W., Conus, W., Hashimoto, K., Huang, Q., A torque limiter for safe joint applied to humanoid robots against falling damage, IEEE International Conference on Robotics and Biomimetics (ROBIO), (2015), pp. 2454-2459.

[72] Lee, W., Choi, J., and Kang, S., Spring-Clutch: A safe torque li lity to reinitialize its position, IEEE/RSJ In l Conference on In (2009), pp. 5140-5145.

[73] Kondo kagaku co. ltd, Servo Motor Product B3M-1100 series: B3M-SC-1170-A (online), available from < http://kondo-robot.com/product/03092>, (accessed on 1st May 2019).

[74] Tanaka, E., Nagayoshi, H., Kondo H., Muramatsu, K., Watanuki, K., Development of a Walking Assistance Apparatus Including a Torque Limiter in a Gear, Proceedings of MPT2017 JSME In –March 3, (2017), Kyoto, Japan.

[75] Budynas, R. G., Nisbett, J. K., Shigley's Mechanical Engineering Design 9th Edition. (2010), p.847, McGraw-Hill.

[76] Sekiya, N., Nagasaki, H., Ito, H., and Furuna, T., Optimal Walking in terms of Variability in Step Length, Journal of Orthopaedic & Sports Physical Therapy, Vol. 26, (1997), pp. 262-272.

[77] Tanaka, E., Yuge, L., Walking assistance according to the emotion, Emotional Engineering Vol. 6: Understanding Motivation (2018), Springer, pp. 140-152.

[78] Tanaka, E., Muramatsu, K., Osawa, Y., Saegusa, S., Yuge, L., Watanuki, K., A walking promotion method using the tuning of a beat sound based on a two-dimensional emotion map, Proceedings of the AHFE 2016 In
-

[79] 's emotion, 2017 IEEE In In
-

[80] -
In

Conference on Affective and Pleasurable Design, Vol. 774 (2018), Springer-Verlag, pp. 158-168.

[81] Posner, J., Russell, J. A., Peterson, B. S., The circumplex model of affect: an integrative approach to affective neuroscience, cognitive development and psychopathology development and psychopathology, Vol. 17, Issue 3 (2005), pp. 715-734.

[82] Bradley, M. M., Lang, P. J., Measuring emotion: the self-assessment manikin and the semantic differential, Journal of Behavior Therapy and Experimental Psychiatry, Vol. 25, Issue 1 (1994), pp. 49-59.

[83] McCraty, R., Shaffer, F., Heart rate variability: new perspectives on physiological mechanisms, Assessment of Self-Regulatory Capacity, and Health risk." Glob Adv Health Med, Vol. 4, Issue 1 (2015), pp.46-61.

[84] Jenke, R., Peer, A., Buss, M., Feature extraction and selection for emotion recognition from EEG, IEEE Transactions on Affective Computing, Vol. 53, No.3 (2014), pp. 327-339.

[85] Javaid, M. M., Yousaf, M. A., Sheikh, Q. Z., Awais, M. M., Saleem, S., Khalid, M., Real-Time EEG-based human emotion recognition, In Information Processing, (2015), pp. 182-190.

[86] Ismail, W. W., Hanif, M., Mohamed, S. B., Hamzah, N., Rizman, Z. I., Human emotion detection via brain waves study by using electroencephalogram (EEG), International Journal on Advanced Science, Engineering and Information Technology, Vol. 6, No. 6 (2016), pp. 1005-1011.

[87] Karegowda, A. G., Manjunath, A. S., Jayaram, M.A., Comparative study of attribute selection using gain ratio and correla lection, In l Journal of Information Technology and Knowledge Management, Vol. 2, No.2 (2010), pp. 271-277.

[88] LeCun, Y, Bengio, Y., Hinton, G., Deep learning. Nature, Vol. 521 (2015), pp. 436-444.

[89] Sutskever, L., Vinyals, O., Le, Q., Sequence to sequence learning with neural networks, Proceedings of the 27th International Conference on Neural Information Processing Systems, Vol. 2 (2014), pp.3104-3112.

[90] Taguchi, G., Objective function and generic function (6), Journal of Quality Engineering Society, Vol. 13, Issue 3 (2005), pp. 5-10 (in Japanese).

[91] Kawada, H., Nagata, Y., An application of a generalized inverse regression estimator to Taguchi's T-Method, Total Quality Science, Vol. 1, Issue 1 (2015), pp. 12-21.

[92] Emotiv Inc., EMOTIV EPOC+ 14 channel mobile EEG (online), available from <h /w >, (accessed on 20 January 2020).

[93] Oisaka Electronic Device Ltd., Feature and function (online), available from < h /w _ function.html>, (accessed on 20 January 2020).

[94] Union Tool, Co., Wireless heartbeat sensor, Type WHS-1/ RRD-1 (online), available from <h /w - >, (accessed on 20 January 2020).

[95] Dunn, D. S., and Dougherty, S. B., Prospects for a Positive Psychology of Rehabilitation. Rehabilitation Psychology, Vol. 50, No. 3, (2005), pp. 305-311.

[96] Karg, M., Samadani, A., Gorbet, R., Kühnlenz, K., Hoey, J. and Kulić, D., Body Movements for Affective Expression: A Survey of Automatic Recognition and Generation. IEEE Transactions on Affective Computing, Vol. 4, No. 4 (2013), pp. 341-359.

[97] Silva, P. R. D., Osano, M., Marasinghe, A. and Madurapperuma, A. P., Towards recognizing emotion with affective dimensions through body gestures," 7th International Conference on Automatic Face and Gesture Recognition (FGR06), (2006), pp. 269-274.

[98] Karg, M., Kulić, D., and Buss, M., Recognition of affect based on gait patterns. IEEE Trans Syst Man Cybern B Cybern, Vol. 40, No. 4 (2010), pp. 1050-1061.

[99] Janssen, D., Schöllhorn, W., Lubienetzki, J., Fölling, K., Kokenge, H. and Davids, K., Recognition of Emotions in Gait Patterns by Means of Artificial Neural Nets. Journal of Nonverbal Behavior,

Vol. 32, Issue 2 (2008), pp. 79-92.

[100] Mizukami, N., Takeuchi, S., Tetsuya, M., Tsukahara, A., Yoshida, K., Matsushima, A., Maruyama, Y., Tako, K., Hashimoto, M., Effect of the Synchronization-Based Control of a Wearable Robot Having a Non-Exoskeletal Structure on the Hemiplegic Gait of Stroke Patients, IEEE Transactions on Neural Systems and Rehabilitation Engineering, Vol. 26, No. 5 (2018), pp. 1011-1016

negative and mixed emotional states: a film library for affective scientists, Cognition and Emotion, Vol. 30, No. 5 (2015), pp. 827-856.

[101] Dal, U., Erdogan, T., Resitoglu, B., Beydagi, H. Determination of preferred walking speed on treadmill may lead to high oxygen cost on treadmill walking, Gait & Posture, Vol. 31, Issue 3 (2010), pp. 366-369

[102] Kolakowska, A., Landowska, A., Szwoch, M., Szwoch, W., Wrobel, M. R., Emotion recognition and its application in software engineering, 6th In I, (2013), pp. 532-539

[103] Kim, J., Kim, K., Cho, S., A sensory control system for adjusting group emotion using bayesian networks and reinforcement learning, The 11th Int. Conf. on HAIS, vol. 9648, (2016), pp. 377-388

[104] Watanabe, T., Saito, H., Koike, E., Nitta, K., A preliminary test of measurement of joint angles and stride length with wireless inertial sensors for wearable gait evaluation system, Comput. In ll. Neurosci., (2011) p. 975193

[105] SANKYO SEISAKUSHO CO., TorqueLimiter Overload Protection Devices- TC series: 4TC (online), available from <h /www.autogard.com/downloads/product-brochures/>, accessed on 20 January 2020.

[106] Mayr Transmissions Ltd., Torque Limiters Products- ROBA® -slip hub (online), available from <https://www.mayr.com/en/products/torque-li >, accessed on 20 January 2020.

[107] Rexnord Industries, LLC., Torque Limiters Products- Series 200: Model 203 (online), available from <http://www.sankyo-seisakusho.co.jp/english/download/manual/index.html>, accessed on 20 January 2020.

[108] Cross+Morse CO., LTD, Torque Limiters and Sheargard Overload Clutches: Models M30-M30-2 (online), available from <http://w - >, accessed on 20 January 2020.

[109] RINGSPANN GmbH, Overload Clutches Products- Friction Torque Limiters: RT 30.1 (online), available from <h /w - - -

[110] IMITED, DAVALL DSG power transmission- Torque Limiter (Overload Protection)- Torque Limiter friction-disc type: DSF 00.25 (online), available from <http://w - - - - - >, accessed on 20 January 2020.

[111] Nakamura, R., Saito, H., Nagasaki, H., Fundamental Kinesiology, Ishiyaku Publishers, Inc., 6th edition (2003), p. 377 (in Japanese)

[112] Maslow, A.H., A theory of human motivation. Psychological Review. Vol.50, No. 4: (1943), pp.370–396.

[113] Bayoumi M., Identification of the needs of haemodialysis patients using the concept of Maslow's hierarchy of needs. Journal of Renal Care. Vol.38, No.1 (2012), pp. 43 – 49.

[114] Jackson, J. C., Santoro, M. J., Ely, T. M., Boehm, L., Kiehl, A. L., Anderson, L. S., Ely, E. W., Improving patient care through the prism of psychology: application of Maslow's hierarchy to sedation, delirium, and early mobility in the intensive care unit. Journal of critical care, Vol. 29, No. 3 (2014), pp. 438–444.

[115] Yang, Q., Classification with Decision Trees I, online lecture, Hong Kong University of Science and Technology, available from < http://www.cse.ust.hk/~qyang/537/PPT/dtrees1.ppt>, accessed on 20 January 2020.

[116] Quinlan, J.R. Induction of decision trees. Machine Learning, Vol. 1, (1986), pp. 81–106

[117] 丹羽涼介，片麻痺患者用歩行補助機の実用化に向けた開発と評価，修士論文 (in Japanese)

[118] Tsiourti, C., Weiss, A., Wac, K., Multimodal Integration of Emotional Signals from Voice, Body, and Context: Effects of (In)Congruence on Emotion Recognition and Attitudes Towards Robots. Int J of Soc Robotics, Vol.11 (2019), pp. 555–573

[119] Boccanfuso L, Wang Q, Leite I, et al. "A thermal emotion classifier for improved human-robot interaction", Robot and Human Interactive Communication (RO-MAN) 2016 25th IEEE In l Symposium on. IEEE, 2016, pp. 718-723.

[120] Chanel G, Kronegg J, Grandjean D, et al. "Emotion assessment: Arousal evaluation using EEG's and peripheral physiological signals", In

-

[121] /www.hocoma.com/solutions/lokomat/, (accessed on 26th Feb. 2019).

[122] Emotiv- frequency band, https://www.emotiv.com/knowledge-base/frequency-bands-what-are-they-and-how-do-i-access-them/, (accessed on 29th Feb. 2019).

[123] Burr, R. L., "In lized spectral heart rate variability indices in sleep research: a critical review." SLEEP 2007;30(7):913-919.

[124] Qaisi, S., Aghazadeh, F., "Electromyography Analysis: Comparison of Maximum Voluntary Contraction Methods for Anterior Deltoid and Trapezius Muscles," Procedia Manufacturing, Vol.3, Pages 4578-4583, 2015

[125] Maas, A. L., Hannun, A. Y., Ng, A. Y., "Rectifier Nonlinearities Improve Neural Network Acoustic Models".2014.

[126] Aniţa, S., Arnăutu, V., Capasso, V., A Tutorial Example for the Gradient Method. An In

–121 (2011).

[127] Bishop, Christopher M. (2006). Pattern Recognition and Machine Learning. Springer.

[128] Ian G., Yoshua B., and Aaron C. (2016). Deep Learning.

[129] Hartigan, J. A., Wong, M. A. (1979). Algorithm: A k-Means Clustering Algorithm. Journal of the Royal Statistical Society, Series C. 28 (1): 100–108.

[130] Zhuang, J. R., Nagayoshi, H., Kondo, H., Muramatsu, K., Watanuki, K. and Tanaka, E., "Development of a Torque Limiter for the Gear of an Assistive Walking Device," Journal of Advanced Mechanical Design, Systems, and Manufacturing, Bulletin of the JSME, Vol. 11, Issue 6, (2017), Paper No.17-00376 (12 pages)

[131] 田中渉，田中英一郎，村松慶一，綿貫啓一，高齢者運動促進用足関節動作補助機における過負荷防止機構の開発，関東学生会第５５回学生員卒業研究発表講演会 (2016), Paper No.710, (in Japanese)

[132] Zhuang, J. R., Nagayoshi, H., Kondo, H., Lee, H. H. and Tanaka, E., "The Applicability of an Assistive Walking Device Integrating Overload Protection Mechanism Using a Torque Limiter," IEEE/ASME International Conference on Advanced In IM 2018), Auckland, New Zealand, July 9-12, (2018), pp.851-856.

[133] Zhuang, J. R., Wu, G. Y., Lee, H. H. and Tanaka, E., "Evaluation of the Walking-Emotion Relationship for Applying to an Assistive Walking Device," 41st Annual In IEEE Engineering in Medicine and Biology Society (EMBC 2019), Berlin, Germany, July 23-27, (2019), pp.3147-3150.

[134] Zhuang, J. R., Guan, Y. J., Nagayoshi, H., Muramatsu, K., Watanuki, K. and Tanaka, E., “Real-Time Emotion Recognition System with Multiple Physiological Signals,” Journal of Advanced Mechanical Design, Systems, and Manufacturing, Bulletin of the JSME, Vol. 13, Issue 4, (2019), Paper No.19-00212 (16 pages)

[135] Zhuang, J. R., Wu, G. Y., Guan, Y. J., Muramatsu, K., Watanuki, K. and Tanaka, E., “Evaluating the In - International Conference on Affective and Pleasurable Design, Washington D.C., USA, July 24-28, (2019), Springer, Cham, Vol. 952, pp.40-47.

[136] Zhuang, J. R., Wu, G. Y., Lee, H. H. and Tanaka, E., “Applying the Interaction of Walking-Emotion to an Assistive Device for Rehabilitation and Exercise,” IEEE/RSJ In l Conference on In lligent Robots and Systems (IROS 2019), Macau, China, November 3-8, (2019), pp.6489-6494.

[137] FSR406, https://www.interli lectronics.com/fsr-406, accessed on 26th Feb. 2019

[138] Corinna, C., Vladimir, N. V., "Support-vector networks", Machine Learning, 20 (3): 273–297, 1995.

[139] Irina, R., “An empirical study of the naive Bayes classifier”, IJCAI Workshop on Empirical Methods in AI,2001.

[140] E. Tanaka, K. Muramatsu, Y. Osawa, K. Watanuki, S. Saegusa, L. Yuge, “Development of a Walking Assistance Apparatus for Promotion of Exercise,” in 4th In ICDES2017, Aachen, Germany, 2017.

[141] Emma Seppälä, Your High-In

[142] lyn Cafasso, Emotional Exhaustion: What It Is and How to Treat It, Healthline, medically reviewed by Timothy J. Legg, PhD, PsyD on April 9, 2019

Research achievements

<Journal>

[1] Zhuang, J. R., Guan, Y. J., Nagayoshi, H., Muramatsu, K., Watanuki, K. and Tanaka, E., Real-time emotion recognition system with multiple physiological signals, Journal of Advanced Mechanical Design, Systems, and Manufacturing, Bulletin of the JSME, Vol. 13, No. 4 (2019), Paper No.19-00212 (16 pages) (Reference [134] in the thesis)

[2] Zhuang, J. R., Nagayoshi, H., Kondo, H., Muramatsu, K., Watanuki, K. and Tanaka, E., Development of a torque limiter for the gear of an assistive walking device, Journal of Advanced Mechanical Design, Systems, and Manufacturing, Bulletin of the JSME, Vol. 11, No. 6 (2017), Paper No.17-00376 (12 pages) (Reference [130] in the thesis)

<International conference (with reviewed)>

[1] Tanaka, E., Zhuang, J. R., Yang, B. R., Wu, G. Y., Lee, H. H. and Yuge, L., A walking assistive device of the ankle joint motion and the control method according to the emotion condition, IEEE/SICE International Symposium on System In II) (2020), (Accepted).

[2] Zhuang, J. R., Wu, G. Y., Lee, H. H. and Tanaka, E., Applying the interaction of walking-emotion to an assistive device for rehabili
ligent Robots and Systems (IROS) (2019), pp.6489-6494. (Reference [136] in the thesis)

[3] Zhuang, J. R., Wu, G. Y., Lee, H. H. and Tanaka, E., Evaluation of the walking-emotion relationship for applying to an assistive walking device, 41st Annual In
IEEE Engineering in Medicine and Biology Society (EMBC) (2019), pp.3147-3150. (Reference [133] in the thesis)

[4] Zhuang, J. R., Wu, G. Y., Guan, Y. J., Muramatsu, K., Watanuki, K. and Tanaka, E., Evaluating the interaction between human walking and two-dimensional emotion variation by using physiological signals, Proceeding of the AHFE 2019 International Conference on Affective and Pleasurable Design (2019), Vol. 952, pp.40-47. (Reference [135] in the thesis)

[5] Lim, C. Y., Zhuang, J. R., Kida, F., Furuta, K., Yasuda, Y., Nakasako, M., Ikejo, K. and Tanaka, E., Development of in-situ portable gear damage diagnostic system using laser reflection, 8th In ICMDT) (2019), TH-B-3-3 (2 pages).

[6] Zhuang, J. R., Nagayoshi, H., Kondo, H., Lee, H. H. and Tanaka, E., The applicability of an assistive walking device integrating overload protection mechanism using a torque limiter, IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM) (2018), pp.851-856. (Reference [132] in the thesis)

[7] Zhuang, J. R., Wu, G. Y., Nagayoshi, H., Yuge, L., Lee, H. H. and Tanaka, E., Two-dimensional emotion evaluation with multiple physiological signals, Proceeding of the AHFE 2018 In -
[80] in the thesis)

<Domestic conference>

[1] 田中英一郎・荘俊融・巫冠論・井上徹夫, "生体信号を用いたリアルタイム感情推定システムの開発", 第二回日本再生医療とリハビリテーション学会学術大会(JSRMR2019), 大阪, 日本, 2019 年 11 月 2 日, p.53.

[2] Wu, G. Y., Zhuang, J. R., Lee, H. H. and Tanaka, E., Human assistance method by connecting two-dimensionally walking condition map to emotion map, the Robotics and Mechatronics Conference (ROBOMECH) (2019), 2P2-M04 (4 pages).

[3] Tanaka, E., Lim, C. Y., Zhuang, J. R., Nakasako, M., Ikejo, K., Practical use of the reasonable and immediate diagnosis system of the gear tooth surface using laser beam reflection, the Robotics and

Mechatronics Conference (ROBOMECH) (2019), 2P2-U04 (4 pages).

[4] Zhuang, J. R., Nagayoshi, H., Kondo, H., Lee, H. H. and Tanaka, E., A safe torque limiter design a
(ROBOMECH) (2018), 2P2-F03 (4 pages).

[5] Guan, Y. J., Zhuang, J. R., Nagayoshi, H., Lee, H. H. and Tanaka, E., Human emotion recognition with multiple physiological signals by deep neural networks, the Robotics and Mechatronics Conference (ROBOMECH) (2018), 1P2-G09 (4 pages).

<Patent>

[1] 田中英一郎・永吉駿人・莊俊融・綿貫啓一・田中渉・近藤博俊, "歯車装置",特開 2018-28388 (P2018-28388A) （公開日：2018 年 2 月 22 日）.