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Article · December 2014

DOI: 10.1109/ICCAS.2014.6987939

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2014 14th International Conference on Control, Automation and Systems (ICCAS 2014)
Oct. 22–25, 2014 in KINTEX, Gyeonggi-do, Korea

Gait Pattern Generation for Robotic Gait Rehabilitation System on Treadmill

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Abstract: Robotic gait rehabilitation devices enable efficient and convenient gait rehabilitation by mimicking the functions of physical theraphists. In manual gait rehabilitation training, physical theraphists have patients practice and memorize normal gait patterns by applying assistive torque to the patient's joint once the patient's gait deviates from the normal gait. Thus, one of the most important factors in robotic gait rehabilitation devices is to determine the assistive torque to the patient's joint during rehabilitation training.
In order to calculate the assistive torque, the desired gait trajectory for affected leg should be determined. This reference trajectory is obtained from his healthy leg. The obtained signal has many noisy factors. Therefore, after conditioning the signal, the suitable pattern is applied to the developed system. This procedure is called "gait pattern generation" in this paper. It is described and discussed in detail.

Keywords: gait rehabilitation, power assist robot,gait pattern.

1. INTRODUCTION

The average lifetime of humans has been increasing, as a consequence the demand for devices to support elderly and disabled people is also increasing. Recent improvements in living conditions have increased the population of elderly and disabled people [1]. Among many daily activities, walking is the most basic and fundamental activity which enables a human being to enjoy his life. Previous efforts to help partially immobilized people to walk without aid has led to the development of gait rehabilitation devices. Immobilization causes profound changes in muscle and bone masses, particularly in the lower limbs. Patients, especially the elderly, are likely to incur additional risk of injury upon reambulation [2]. Early mobilization has been proven useful in preventing contracture of the lower limbs [3]. This approach may avoid or reduce several drawbacks associated with pathologies, including osteoporosis, spasticity, and bedsores. As these subjects are often unable to exert the muscular force necessary to maintain their posture and ambulate, it is essential to provide them with robotic system for gait balancing and rehabilitation.

Devices for gait rehabilitation require specific weight unloading and walking speed adjustment with respect to the degree of disability [4][5][6]. In medical centers or rehabilitation facilities, nurses and physiotherapists assist gait training for subjects with the traditional tools for weight support such as canes and crutches in a static condition to improve their muscular activation capability and their sense of balance. Although these efforts improve the general condition of patients, some gait anomalies nonetheless remain after treatment. With the traditional tools, the amount of weight support is neither constant nor quantifiable because it depends on the strength of the patient as well as their degree of control of their upper limbs and trunk.

Treadmill walking is used as a substitute to level ground walking since not only it appears to be an effective clinical tool, but also it offers some practical advantages over level ground gait retraining. For instance, treadmill gait retraining uses less space and is relatively simple to apply this technique in less functional patients with the use of weight support. Studies have shown that walking on a treadmill does not significantly change the gait pattern compared to overground walking and that improvements achieved during treadmill gait retraining transfer to overground walking.

In the present research, a gait rehabilitation robot systems is designed. In order to control and evaluate the developed platform, the gait pattern was generated for each individual. The paper is arranged in the following order: Section 2describe she system architecture and the controller design. Section 3discusses how to define and generation a gait pattern. Concluding remarks and further developmental issues are discussed in Section 4.

2. SYSTEM DESCRIPTION

The developing gait rehabilitation system is shown in figure 1. It is a power assist robot for supporting the hip/knee/ankle torque for walking.

2.1 Robotic gait rehabilitation

Stroke causes physiological as well as neurological changes in the body. These physical changes result in abnormal gait patterns. Some patients have decreased muscle activation on the affected side and need compensatory strategies to maintain balance. Others have increased and/or inappropriate muscle activation and dis-

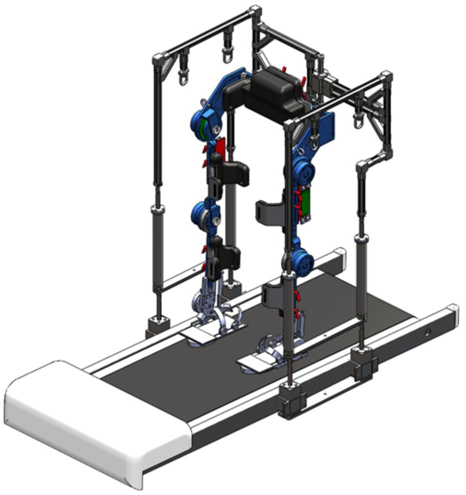


Fig. 1 The developing robotic platform.

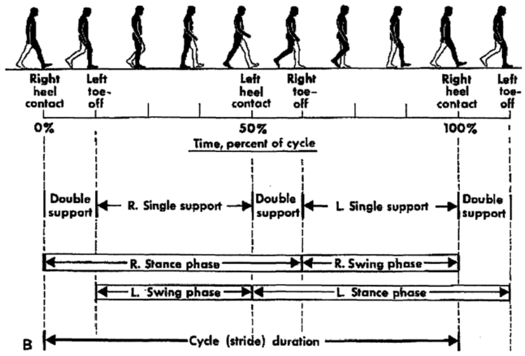
rupts the sequence of gait movements [7].

The goal of gait rehabilitation training is for patients that suffer from gait disorders to restore locomotion through rehabilitation of their degenerated muscular or neural functions. By applying assistive torque to the patient's joint, a patient can either practice the desired gait trajectory for rehabilitation or strengthen muscles. If the patient's problem is an inability to supply sufficient muscle strength to meet the demands of desired gait motion, then the patient needs assistive torque in order to achieve the desired motion. In this case, the gait rehabilitation strategies that emphasize the recovery of muscular forces are required. Applying appropriate resistive torque to strengthen muscles is one of the possible rehabilitation strategies. Patients with impaired nerve systems, e.g. spinal cord injury (SCI) or stroke, cannot control their muscles due to abnormal motor control signals. For these patients, physical therapists apply voice or force feedback to patients during gait rehabilitation training. Through force or voice feedback, physical therapists educate patients of normal joint trajectory and also physically guide patients to the desired joint trajectory for rehabilitation. In this paper, the gait rehabilitation strategy on how to determine assistive torque in robotic gait rehabilitation devices in order to practice a rehabilitative gait trajectory is discussed.

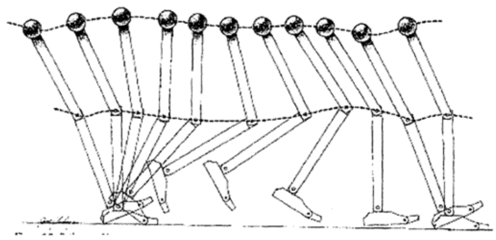
3. GAIT PATTERN GENERATION

3.1 Gait pattern definition

The phase of gait shown in figure 2 and the six elements of gait described by Inman *et al.* [8] combine for a simple yet useful description of gait kinematics. A gait cycle is defined as the time between subsequent right heel contacts. Each gait cycle includes two periods of single



(a)Time dimensions of walking cycle



(b)Pathway of knee and hip during gait

Fig. 2 Gait pattern.

support and two period of double support. A leg in contract with the ground is called a stance leg and one that is not in contact with the ground is called a swing leg. At about 25% on the gait cycle the person is the right single support phase, the right leg is the stance leg and the left leg is the swing leg.

The normal knee motion in one stride is shown in figure 3 with corresponding gait phases. Normal knee angles during walking are within the range of 0° to 70° as shown in figure 3. At initial contact phase, the knee is flexed about 5°. In loading response phase, putting body weight on the limb instantly disturbs the knee's stability. The knee flexion, however, provides shock absorption in load response phase. Throughout the loading phase, the knee is rapidly flexed. In the rest of the stance, the knee extends and the ankle dorsiflexes in order to propel the body mass forward. In swing, the knee is flexed to lift the foot for limb advancement. This is the critical action that ensures foot clearance as the limb swings forward from the trailing posture.

3.2 Gait pattern generation

Gait pattern is gathered from motion captured data of a healthy. The developed rehabilitation robot for lower body is powered on hip and knee joints by the electric motor. Therefore, the desired trajectory for hip and knee is applied to the robotic system during gait rehabilitation. In order to generated the desired trajectory for each joint, the motion profile is captured from the motion capture system as shown in figure 4. Training data is gathered from motion profile of one gait cycle. It is sampled at

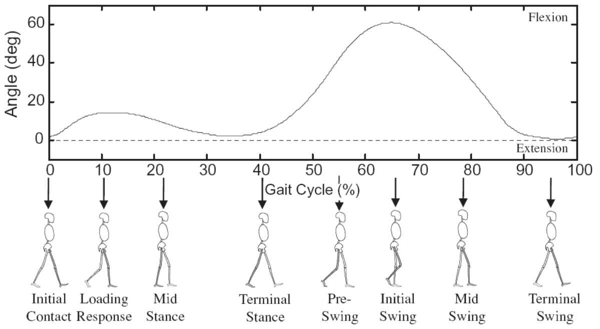


Fig. 3 Normal knee angle in one stride and corresponding gait phase

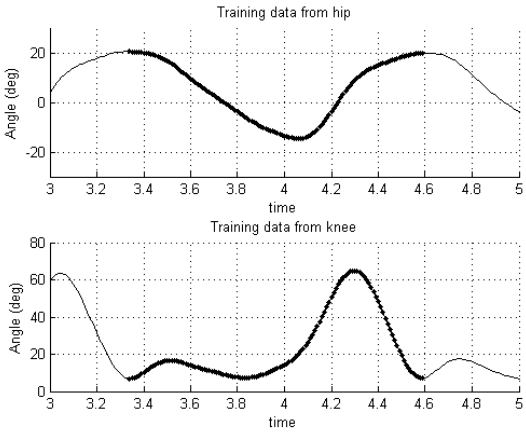


Fig. 4 Training data generation from motion captured data. An upper plot is for hip joint, and a lower plot is for knee. The training data is gathered from one gait cycle.

intervals of 10 milliseconds on the condition of 3.2km/h speeds on the ground. An upper plot is for hip joint, and a lower plot is for knee.

As shown in figure 4, it is hard to describe the gait pattern into the numerical function. Therefore, the radial basis function neural networks (RBFs) is suitable to learn and estimate it. A RBFs is an artificial neural network that uses radial basis functions as activation functions. The output of the network is a linear combination of radial basis functions of the inputs and neuron parameters. Two RBFs were used for learning hip and knee joint patterns. Each RBFs consists of 50 neurons in hidden layer. The result of learning gait pattern data is shown in figure 5. The RBFs may estimate the unknown values through the whole period. It means that the system designer can make the modified gait pattern including the individual characteristics. In this paper, individual characteristics mean the walking speed, gait cycle period, gait phase changes, and so on.

For checking the performance of gait pattern generation, the arbitrary gait motion was made as shown in figure 6. The arbitrary gait motion can be generated from the RBFs. The amplitude and period of gait are modified by

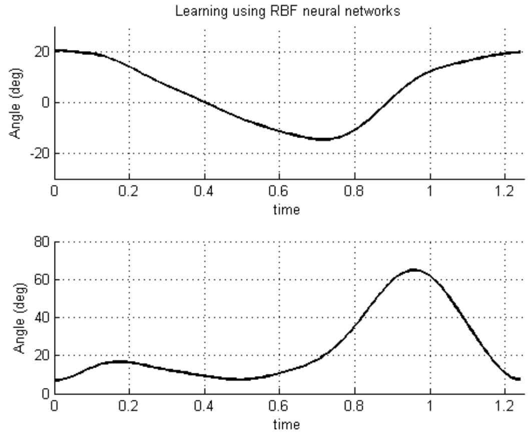


Fig. 5 Learning using RBF neural networks. Each RBFs was trained with motion data for hip and knee. 50 neurons were used for each RBFs.

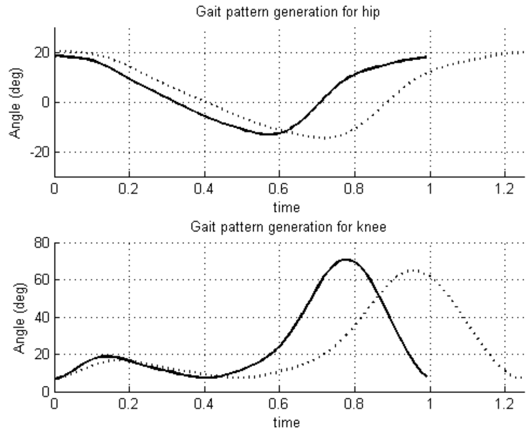


Fig. 6 Gait pattern generation. The arbitrary gait motion can be generated from the RBFs. The amplitude and period of gait are modified by system controller. (dotted line: original pattern, solid line: modified pattern)

system controller. In this figure, the dotted line means the original pattern (pattern used for training), and the solid line is the modified pattern.

3.3 Implementation on robotic gait rehabilitation system

It is assumed that the target patients are suffering from hemiplegia. Hemiplegia means severe weakness of the limbs on one side of the body. In order to become worse, the physical exercise is one of the most important things for the patients to do. The robotic system was designed to support the torque of a weakened limb according to the patient's rehabilitation degree. Therefore, the torque (power) from robotic system should be controlled automatically and continuously.

Exoskeleton-type robotic system was developed to gather the gait pattern from a healthy leg and to support the torque for a impaired leg as shown in figure 7. The whole robotic system was hanged on outer frame with

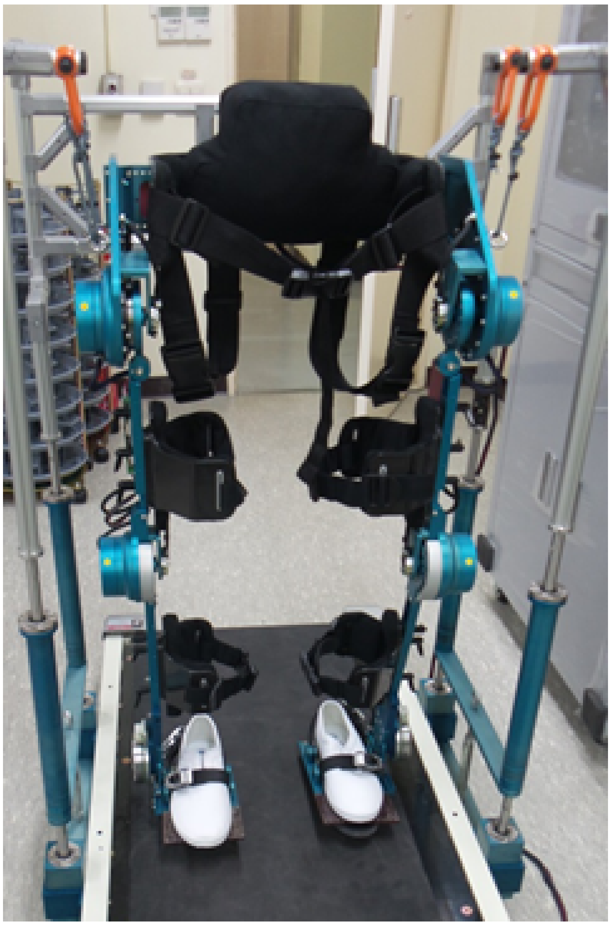


Fig. 7 The developed robotic gait rehabilitation system.

harness. Also, it was controlled to operate simultaneously with treadmill. Three DOFs (hip, knee, ankle) were applied for each leg.

Figure 8 shows the experimental results for the gait pattern generation for impaired leg after gait adaptation from a healthy leg. The reference data from a healthy leg can be adapted from the proposed algorithm and the time difference between each gait cycle can be calculated. The half time was applied for the gait phase difference between a impaired leg and a heathy leg. Through the whole procedure, the robotic system and treadmill can be controlled simultaneously according to the patient's intention.

As shown in figure 10, assistive torque is controlled according to the harmness/rehabilitation degree in the developed system. Two cases are compared according to the assistive torque on the impaired leg. The treadmil speed of 1 m/sec is fixed on this experiments. Just, the assistive torque was set on 60% and 80% supporting. First figure shows the experimental results when the 80% supporting was set on an impaired leg. The second experimental results shows the 60% supporting is applied on the same operation conditions.. As shown in figure 10, the trajectory can be changed according to the assistvive torque.

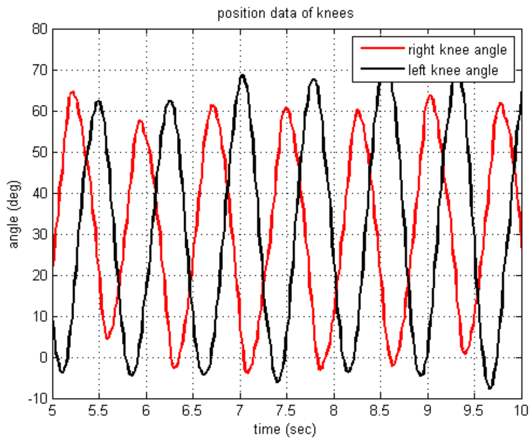


Fig. 8 Gait pattern generation and phase adaptation for impaired leg. The gait data was gathered from a healthy leg (left leg). It was adapted using the proposed algorithm/processes. And, the gait pattern was generated for the impaired leg (right leg)

4. CONCLUSION

Here we presented a gait rehabilitation systems that enable gait training on treadmil. Also, the proposed gait pattern generation algorithm was implemented on it. In real time, the desired gait pattern was determined and applied to the desired trajectory for the impaired leg using proposed algorithm. According to the applied assistive torque, the supporting torque is determined. Therefore, the patient with little demage can exercise with low supporting torque. It means that each patient can adjust the supporting torque on his own authority. Experimental results shows that the proposed algorithm was effectively implemented on developed robotic system.

ACKNOWLEDGMENT

This research was partially supported by

Ministry of Knowledge Economy (MKE), Korea Institute for Advancement of Technology (KIAT) and Daekyung Leading Industry Office through the Leading Industry Development for Economic Region,

Ministry of Culture, Sports and Tourism(MCST) and Korea Creative Content Agency(KOCCA) in the Culture Technology(CT) Research & Development Program (Immersive Game Contents CT Co-Research Center),

Ministry of Knowledge Economy (MKE), Korea Institute for Advancement of Technology (KIAT) and Biomedical IT Convergence Center.

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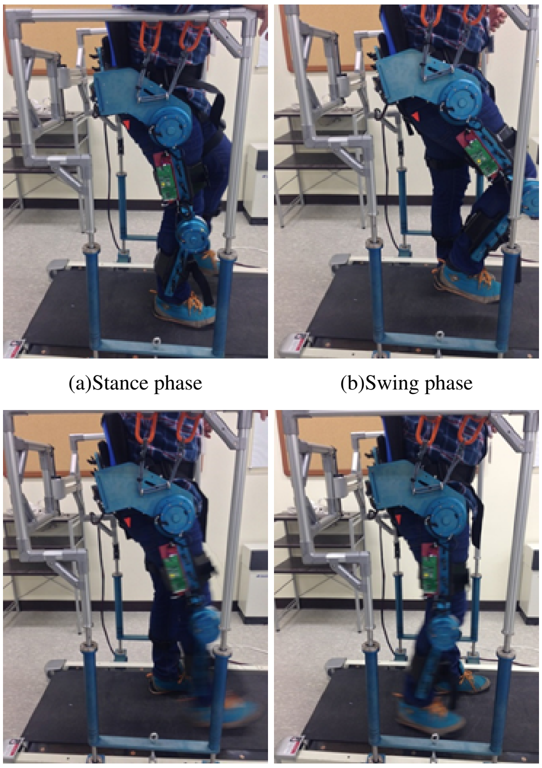

(a)Stance phase (b)Swing phase

(c)Heel strike (d)Toe off

Fig. 9 Implementation on robotic gait rehabilitation system.

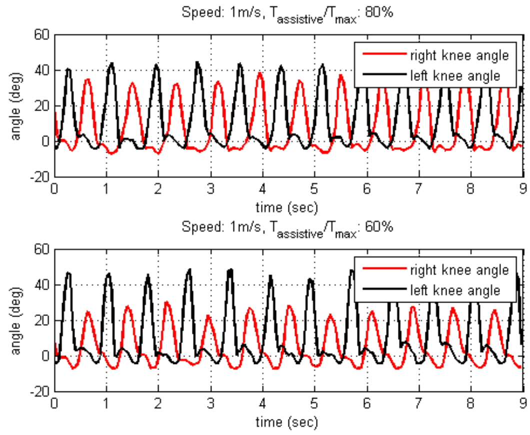

Fig. 10 In the developed system, assistive torque is controlled according to the harmness/rehabilitation degree.

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