Trajectory Generation for Hip Rehabilitation Exoskeleton Using Trajectory Morphing Method

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ABSTRACT – A walking rehabilitation exoskeleton robot is used for patient having walking difficulty to undergo walking therapy by wearing it on his lower body. If the rehabilitation is done directly by using predefined normal gait, the patient can feel discomfort and may lead to painful therapy. This can also endangered the patient limb under therapy. Due to that reason, the patient will be discouraged and unmotivated to proceed with the therapy. This paper presents the hip trajectory generation by utilizing the patient current trajectory that morphs into the target trajectory by generating a sequence of gradually changing hip trajectories.

1. INTRODUCTION

Trajectory generation is the process of producing a trajectory profile to be used as reference and followed by targeted joints of rehabilitation exoskeleton with trajectory tracking strategy where, walking trajectory must be available to control the exoskeleton to produce human like movement for the patient undergoing the therapy.

Some researchers have generated [1,2] or planned [3,4] the trajectories based on recorded human gait, sensed human gait, polynomial based and online/offline learning [5]. However in these researches, no consideration has been made on the original state of the patient walking profile to be included in the trajectory generation.

Consequently, there is a large gap between the patient current abnormal walking trajectory and the intended normal walking trajectory. To achieve the target, patient may undergo a painful and stressful therapy sessions as there is no gradual shift of abnormal walking trajectory to the normal walking trajectory. The exoskeleton worn will force the patient to follow the normal walking trajectory sharply.

In this rehabilitation therapy, normative hip trajectory is taken as reference and compared with the specific current trajectory of the elderly or patients with hip problems. The reference trajectory may not differ much from person to person but the abnormal trajectory is person specific. Focusing on the hip joint, a series of hip trajectories that gradually shift abnormal hip trajectory towards the target normal hip trajectory is generated.

2. METHODOLOGY

The trajectory to be generated is the hip position angle trajectory through a morphing method from a trajectory to another trajectory. The trajectory morphing is obtained by the mapping of the abnormal hip trajectory onto normal hip trajectory so as the abnormal trajectory changes shape to resemble the normal trajectory. In between the two initial trajectories, a series of trajectories is generated.

For this trajectory generation, the normal trajectory data is taken from the mean of a normative data [6] and abnormal trajectory data taken from the actual patient data [7] in one gait cycle. The abnormal trajectory is a trajectory deviation from the normal trajectory. One gait cycle or 100% gait is taken from toe off to the next toe off of a leg. A stride time is defined as time taken in seconds to complete a gait cycle or a period taken over 100% gait.

Both data are approximated using quintic polynomial equations [8] as Equation (1) for normal trajectory and Equation (2) for abnormal trajectory.

$$y = 10^3 \begin{pmatrix} -1.2820x^5 + 2.2247\,x^4 - 0.8060\,x^3 \\ -0.1257x^2 - 0.0144x + 0.0334 \end{pmatrix} \quad (1)$$

for $0.02 \leq x \leq 1$

$$y = \begin{pmatrix} -5.1326x^5 + 28.6548x^4 - 42.1360x^3 \\ +14.1871x^2 - 22.0544x + 45.8206 \end{pmatrix} \quad (2)$$

for $0.06 \leq x \leq 3$

The stride times for normal and abnormal are different although the gait cycle is always fixed. A gait cycle may have different stride time for different patient conditions. The stride time for a normal person is shorter than the stride time for abnormal person. Figure 1 shows the plots of the normal and abnormal trajectories hip trajectories plotted on the same graph based on the longer stride time. In hip rehabilitation therapy, the shorter stride time is the target to achieve.

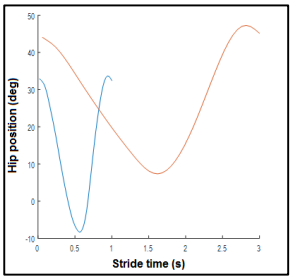

Figure 1 Normal and abnormal hip trajectories

The trajectories are based on numerical dataset consisting of hip joint angle versus time obtained from clinical gait analysis (CGA) data. Table 1 shows the hip joint position range or the range of motion (RoM) and the stride time for both profiles.

Table 1 Properties for both profiles

Properties	Hip position Range (deg.)	Stride Time (s)
Abnormal	7.37 – 47.29	3
Normal	-8.31 – 33.69	1

Both trajectories in Figure 1 are interpolated and divided into 50 points of fixed interval each. A point-to-point mapping of normal and abnormal joint trajectories is applied where point 1 on abnormal trajectory is mapped linearly onto point 1 on normal trajectory sequentially until point 50 along both trajectories as illustrated in Figure 2.

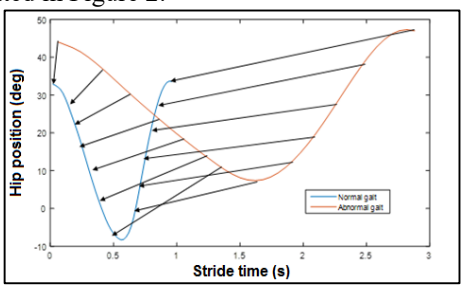

Figure 2 Point-to-point mapping from abnormal to normal trajectory

As a result, there are 50 lines where each line is divided into 10 points starting from point 1 on abnormal trajectory sequentially to point 10 on normal trajectory. Each point 1 on all lines is connected from line 1 up to line 50 to form a curve. These are repeated every time until point 10 to form sequence of eight trajectories as shown in Figure 3 with each trajectory used for a therapy session. The generated trajectories lie within the normal and abnormal trajectories. Hip trajectories have been produced for gradual hip rehabilitation therapy sessions moving from abnormal to normal trajectory.

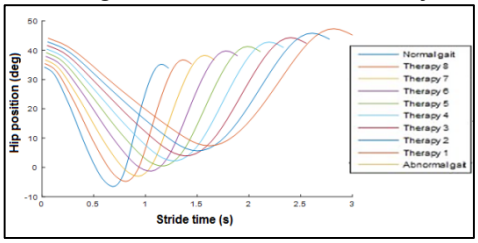

Figure 3 Generated series of trajectories between normal and abnormal trajectories

3. RESULTS AND DISCUSSION

The generated trajectories gradually move or shifted successively from abnormal trajectory towards normal trajectory thus reducing also the stride time. Stride time has been reduced gradually from 3s to 1s in ten successive trajectories.

4. CONCLUSIONS

The generated successive trajectories can be used in planning a hip rehabilitation therapy number of sessions within a specified duration. In each session one trajectory can be selected for use as reference input to hip rehabilitation exoskeleton in guiding patient wearing the exoskeleton. In subsequent therapy session, the selected trajectory is changed to gradually match the normal trajectory throughout the rehabilitation course.This method can help reduce the therapy sessions burden on the patient and helps the therapist to plan for the hip rehabilitation therapy process effectively. Through this method, a patient recovery plan can be produced and the expected time or duration for recovery can be predicted. The patient can experience painless rehabilitation therapy session and fast recovery with planned rehabilitation course as each therapy session is according to the patient recovery performance.

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