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Simple method to reduce the effect of patient positioning variation on three-dimensional motion analysis during treadmill gait

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Abstract

Recently, three-dimensional (3D) closed curve trajectories of markers placed at strategic body locations, called *cyclograms* or *Lissajous-like graphs*, are used for treadmill gait analysis. A simple method is presented to reduce the effect of patient positioning variation. After breaking down movement into three components (anterior-posterior, medial-lateral and superior-inferior), the time-series data and time-inverted data are serially concatenated. A fast Fourier transform (FFT) is done, and a high-pass filter (except 0 Hz) is applied to the anterior-posterior and medial-lateral components. Next an inverse FFT is executed, and the posterior half of the outcome, corresponding to time-inverted data, is deleted. The 3D closed curve is then reconstructed. Results showed that the proposed method was able to reduce the effect of patient positioning variation. Since the adjusted curve is simply a symbolized gait pattern, the method might be useful as an adjunct tool in observational gait analysis.

Introduction

Bipedal ambulation is one of the most common human physical activities. In the clinical setting, many patients with neurological or orthopedic disorders demonstrate disturbances in gait. Gait exercise on a treadmill is effective rehabilitation after neurological assault.[1-3] In addition, treadmill exercise has been combined with robotic assistance and/or functional electrical stimulation.[4] In order to evaluate the effects of exercise and to determine optimal exercise conditions, it is necessary to objectively clarify the ambulation capacity of each patient. Some spatiotemporal parameters (swing time, stance time, double support time, etc.) measured by a motion analysis system have been used in previous studies.[5-8] Recently, three-dimensional (3D) closed curves of the trajectories of markers placed on body landmarks, called *cyclograms* or *Lissajous-like graphs*, have been used for gait analysis.[9-11] Since the measurements are acquired on a treadmill, each marker returns to almost the same position after one stride cycle, and consequently, the path forms a closed curve. In general, the curves are used after decomposing them into three planes (frontal, sagittal, and horizontal). Because the curves indicate human motion patterns, physicians and therapists can interpret gait patterns from the curves. However, it is difficult to apply this study method to gait disorders because this methodology assumes that patients walk in a consistent position which cannot be guaranteed. Even in healthy persons, the positioning of anterior-posterior and medial-lateral directions vary from stride to stride, thus causing drifts of curves (Figure 1).[12]

The drifts can distort the curve shape and increase the standard deviation of averaged curves. Such drifts might obscure the specific or pathognomonic points of curves. This paper presents a simple method to reduce the effect of patient positioning variation on 3D motion analysis data during treadmill gait. The method uses a fast Fourier transform (FFT) and high-pass filter, and is expected to help motion analysis using 3D closed curves in gait disorders.

Materials and Methods

Ethics approval

The ethics committee of the Fujita Health University approved the study protocol (No. 09-028). The experiment was conducted in accordance with the 1975 Declaration of Helsinki (rev 2008).

Experimental procedure

One healthy young subject with no history of neurological or orthopedic disorders, who was expert with substantial experience treating various gait disorders, participated in the experiment. Prior to data collection, the subject gave written informed consent after thorough explanation of the study. The subject walked on a treadmill (Adal 3D, Medical Development, Nantes, France) with a colored marker placed on the right lateral malleolus. The subject was instructed to mimic a gait disorder defined as fluctuation in the positioning in the anterior-posterior and medial-lateral directions. The belt speed was set at 4.0 km/h. Before obtaining measurements, practice tri-als were allowed for the subject to become familiar with a disordered gait. After familiarization, the marker trajectory was collected by a motion capture system (Motion recorder, Kissei Comtec Co., Ltd, Nagano, Japan) at a sampling frequency of 60 Hz. Standard data processing was performed using KineAnalyzer software accompanying the device.

Processing method

The proposed method is composed of five steps. First, after decomposing the motion into three components (anterior-posterior, medial-lateral and superior-inferior), each time-series data and time-inverted data are serially concatenated because the method uses a FFT algorithm that assumes that the signal is periodic, thus beginning and ending with the same value, otherwise spectral leakage artifacts would occur. Second, FFT computation with a rectangular window function is used to obtain the frequency spectrum. Third, a high-pass filter is applied to the anterior-posterior and medial-lateral components of the data (not applied to the superior-inferior component). Specifically, part of the low frequency band [up to one-third of the gait cycle frequency (except 0 Hz)] is replaced with zeroes since this where the positioning fluctuation occurs. Fourth, the inverse FFT computation reconverts the frequency spectrum to time-series data. Finally, after deleting the posterior half of the data (corresponding to inverted time-series data), the 3D closed curve is reconstructed.

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Results

Figure 2 shows the waveform at each processing step in the sagittal plane.

In the first step, the first and last points of the waveform became the same value by coupling to the inverted time-series data. In the third step, the proposed method selectively removed noise content (low frequency band) resulting from positioning fluctuation.

Figure 3 shows the closed curves in the sagittal and the horizontal planes, respectively.

The noise caused by fluctuation in positioning in the anterior-posterior and medial-lateral directions was removed by application of the proposed method.

Discussion

The results suggest that the proposed method is able to reduce the effect of patient positioning variation on the 3D closed curve measured during treadmill gait. In theory, variations of each marker made up of two independent components. One is the variation of gait pattern itself. It is expressed in per-cycle variation of marker position relative to center of gravity. The other is the variation of patient position. It is caused by the variation of gait speed (anterior-posterior component) and a decrease of straight-walking stability (medial-lateral component). Although both components have important clinical implications, first step in the gait analysis should be to evaluate the variation of gait pattern after removal of the effect of patient positioning variation. Since the two components differ in frequency, the latter may be selectively filtered. In particular, the frequency of gait pattern variation is higher than gait cycle whereas sufficiently lower in patient positioning variation. In the proposed method, the gait pattern is cleared up by high-pass filter [one-third of the gait cycle frequency (except 0 Hz)] for reducing the effect of patient positioning variation.

Previous studies examined the time variability of gait parameter in various gait disorders. Patients with Parkinson's disease have greater variability in step time[13] and stride time.[14] Post-stroke patients have variability in stride time compared to control subjects.[15] Patients with cerebral palsy also display increased variability of step time and corresponding higher center of pressure dispersion
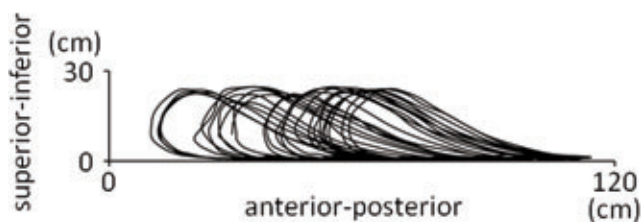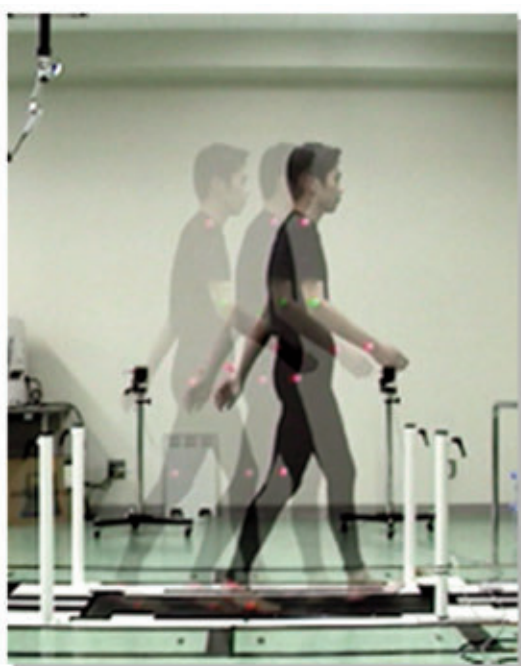

Figure 2. Waveform at each processing step.

Figure 1. Typical example of the effect of fluctuation in the positioning of anterior-posterior direction on the marker trajectory of the right lateral malleolus in the sagittal plane.
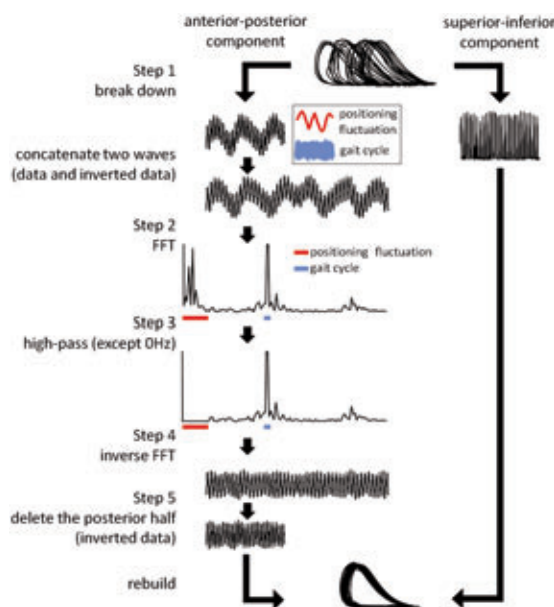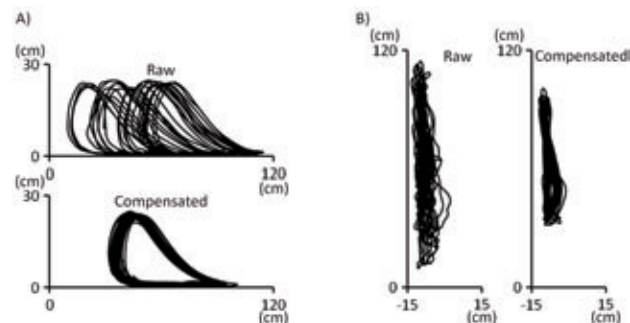

Figure 3. Raw and compensated marker trajectories attached to the right lateral malleolus. A) View from the sagittal plane. B) View from the horizontal plane.

relative to unaffected subjects.[16] Since time variability might cause the patient positioning variation, the proposed method is especially important in measuring gait in those affected with these disorders.

Compensating 3D closed curves with the proposed method might hold great promise for improving the efficacy of observation gait analysis that is widely used in clinical practice. Physicians and therapists generally perform pattern recognition in gait disturbances to plan patients' treatments. However, observation analysis does require a higher skill level. In detecting gait anomalies in unilateral below-knee amputees using observation versus biomechanical analysis, the pick-up rate by observation was 22.2% when compared with biomechanical analysis.[17] When comparing visual and 3D gait analysis in patients with cerebral palsy, only two out of ten anomaly points could be similarly evaluated by both methods.[18] Brunnekreef et al.[19] suggest that a great deal of experience in observation gait analysis is required to improve observation skills. In other words, *some* experience is not sufficient; only expert raters accomplish significantly better reliability levels of visual gait observation compared to inexperienced raters. Although the unmanipulated 3D closed curve is distorted by the effect of patient positioning variation, the compensation provided by the proposed method reduces the shape complexity to the symbolized gait pattern that has great understandability. Therefore, it might be useful as an adjunct tool in gait pattern recognition.

Some limitations have to be addressed in future work. First, large number of repeated measurements is required to clarify intra- and inter-subject variability. Second, a wide variety of disorders should be measured since gait abnormality might be affected by type of disorder. Third, the processing method should be analyzed in detail. The serially concatenated data (time-series data and inverted data) was used to conform the last point of the signal to the first point. However, the data introduces a discontinuity in the first time-derivative at the concatenation point. It might have effects on an amplitude spectrum of the signal using FFT.

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