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IDENTIFICATION OF SIMULATED ANKLE SPRIAN FROM COMMON SPORTS MOTIONS BY FFT AND POLYNOMIAL FITTING ON DORSAL FOOT KINEMATICS DATA

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This study presented a method to identify simulated ankle sprain motion from common sporting motions by using motion sensor data. Five subjects performed 100 simulated sprain trials and 245 non-sprain common sporting motion trials in a laboratory. Eight motion sensors were attached to different anatomical landmarks on the right foot to collect 3-D linear acceleration and angular velocity data, which was then processed by fast Fourier transform and polynomial fitting in frequency domain. The coefficients of fitted curve were compared, and the accuracy to identify ankle sprain motion achieved 97.0%. Comparing to a previous method, the current method requires shorter data collection and computation time, and could serve for real time ankle sprain monitoring.

KEY WORDS: sports medicine, injury biomechanics, ankle inversion, motion sensing

INTRODUCTION: Ankle inversion ligamentous sprain is one of the most common sports injuries (Fong, Hong, Chan, Yung, & Chan, 2007), in which human response is not fast enough to accommodate the sudden change of ankle movement. In order to prevent the injury, bracing and taping are widely used by athletes (Hume & Gerrard, 1998). However, these methods are passive, and they restrict the agility of ankle joint motion and limit the performance in sports. Our research team has developed a technology to assist peroneal muscle contraction to prevent an ankle sprain injury (Fong, 2012). The technology only provides the corrective action when in need, and does not hinder the ankle joint agility and thus the sports performance. The success of the anti-sprain system relies on the ankle sprain identification algorithm, which has to be accuracy and quick enough to actuate the corrective mechanism. Our previous study showed an accuracy of 91.3% in identifying ankle sprain motions by a trained support vector machine (SVM) model (Chan et al., 2010). However, this method required a data collection time of 1 second, so it would not be practical to implement this method in the anti-sprain device as it would not be fast enough to actuatue the corrective mechanism in time, to catch up the duration of a sprain injury, which was reported to be around 40ms (Fong, Chan, Mok, Yung, & Chan, 2009). Therefore, there is a need to develop new methods for faster identification for the sake of successful ankle sprain prevention.
This paper presents a new identification system to identify ankle sprain supination sprain motions from vertical jump, stepping down from a stair, cutting, running and walking trials by applying fast Fourier transform and polynomial fitting in the frequency domain with the dorsal foot kinematics data collected by tri-axial accelerometers and gyrometers.

METHODS: Five adult male subjects (age = 22 $\pm$ 1.7 years old, height = 1.75 $\pm$ 0.04 m, body mass = 69.7 $\pm$ 2.8 kg) participated in this study. A total of 100 simulated supination sprain motions were performed simulated inversion and supination sprain trials on a pair of sprain simulators which replicated ankle sprain motions with different combinations of plantarflexion and inversion (Chan, Fong, Yung, Fung, & Chan, 2008). They were instructed to evenly distribute their weights on both feet when they stood on the platforms, and one of the platforms fell suddenly without notifying the subject. Only the trials with the fall on the right limb were included. Another 245 valid trials of common sporting motions, including cutting, stepping down from a step, vertical jump-landing, running and walking trials, were also performed. These motions were specially selected because most ankle sprain injuries happened in these sporting activities and were incorrectly identified by our previous attempts in using trained SVM model.

Eight wired motion sensors (Sengital Ltd., Hong Kong) were attached to several anatomical landmarks on the left foot, including hallux, first proximal metatarsal head, fifth distal metatarsal head, fifth proximal metatarsal head, medial calcaneus, posterior calcaneus, lateral malleolus and tibia. Each sensor contains a 500Hz sampling tri-axial accelerometer (A_x,A_y,A_z) and gyrometer (G_x,G_y,G_z), which collect three dimensional linear accelerations and angular velocities. In 3-dimensional motions, components of different axis can be combined into single magnitude by

Pythagoras theorem:

$$|q| = \sqrt{q_x^2 + q_y^2 + q_z^2} \quad -(1)$$

Figure 1: Experimental setup for data collection on ankle sprain motion

q - magnitude of a motion (acceleration A and angular velocity G in this experiment)

q_i – magnitude of the i-th axis component

Combined magnitude q would be the signal that to be analyzed, which direction of acceleration and rotation would be eliminated in this step.

Fast Fourier transform (FFT) is an algorithm to compute discrete Fourier transforms (DFT) and find the inverse. Mathematically the transform on N points can be represented as:

$$X(k) = \sum_{j=1}^{N} x(j)\omega_N^{(j-1)(k-1)} \quad -(2)$$

where $\omega_N = e^{-\frac{2\pi i}{N}}$ is an N-th root of unity.

Trimmed data were converted from time domain to frequency domain by FFT function in Matlab (Version R2012a, MathWorks, Inc., Natick, Massachusetts, USA). A set of complex amplitudes ($\{a_i\}$) was generated by previous process, which then applied with a logarithmic function on its modulus ($\{|a_i|\}$). The rescaling procedure was necessary for order of magnitude of modulus ($\{|a_i|\}$) varied from 10^2 to 10^4, which the rescale equation was

$$\{|a_i|\} = 10\log\{a_i\} \quad -(3)$$

Spectrums of the motions in frequency space were hardly recognized by naked eyes. Thus a polynomial curve fitting was applied on the converted data in frequency domain. Polynomial order of 5 was tested in the experiment, in order to find a suitable threshold in coefficient that can differentiate ankle sprain motions from the non-sprain one.

RESULTS: The first order coefficients obtained from polynomial fitting were significantly different when comparing different motions (Table 1). Ankle sprain motions had a mean value for the first coefficient differed from the non-sprain motions. Angular velocity data collected by sensors at first proximal metatarsal head was first to be examined.

By examining the coefficients in different motions, numerical value for the 1st order coefficient larger than -0.38 was determined to be an ankle sprain case, which 97.0% of ankle sprain data was correctly identified. This value was chosen for most result can be included in the identifcation process, where the class for simulated supination motion was (-0.38,0.24).

Average fitted curve of different motions was presented in Figure 2, showed the deviation of spectrum in frequency space. Angle of supination was not important for the identification of ankle sprain motion. Similarly we can set than whenever the 1st order coefficient was smaller than -0.38, the data was identified to be non-sprain motions. 91.4% of non-sprain motions were included with same scheme, meanwhile excluding the vertical-jump data. Jumping data were hardly differentiate by inspecting 1st order coefficient generated by the gyrometer data collected, successful identification by setting threshold at -0.38 only contribute 67.3% accuracy of correct identification.

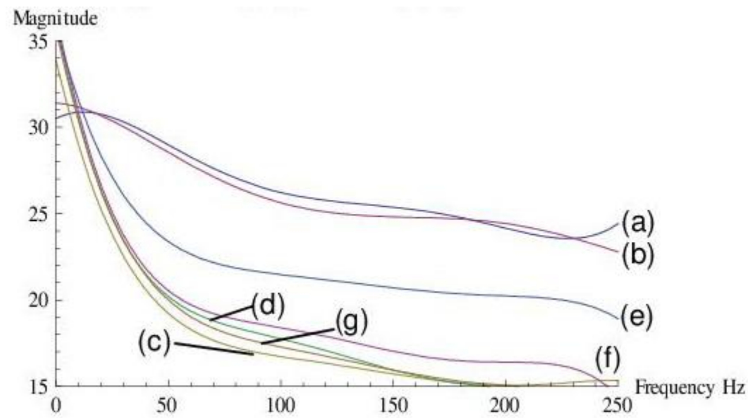
Table 1: 1st order coefficients obtained by polynomial fitting on spectrum in frequency space ($x10^{-2}$)

Simulated inversion sprain	6.8 ± 4.9
Simulated supination sprain	-0.7 ± 3.1
Cutting	-56.5 ± 4.9
Stepping down from a step	-67.2 ± 2.8
Vertical jump-landing	-49.3 ± 3.9
Running	-67.3 ± 2.5
Walking	-61.8 ± 3.7

Table 2: Results of correct identification by setting 1st order polynomial fitting coefficient threshold at -0.4

	Percentage of correct identification
Simulated inversion and supination sprain trials	97.0%
Cutting, stepping down from a step, running and walking	91.4%
Vertical jump-landing	67.3%

Figure 2: Average curve on a fifth order polynomial fitting in frequency space of different motions: (a)simulated inversion (b)supination sprain trials (c)cutting (d)stepping down from a step (e)vertical jump-landing (f)running (g)walking (h)combined result



DISCUSSION: From the result in Table 2, the current method correctly identified 97.0% simulated ankle sprain motions and 91.4% of non-sprain motions, excluding jumping trials. This was an improvement from previous studies by using SVM method (Chan et al., 2010). With the same set of collected data, we may use different approaches to obtain different result. This study aimed at reducing misidentification from methods developed in other researches. Based on the study objective, the result of the new method was encouraging, which a further study can be done with this foundation.

A very short period of time window was chosen in this research that only involved 0.11 second. We attempted to achieve real time data processing and identification, which can prevent ankle sprain by just monitoring the kinematic data in preinjury phase. Most previous studies evaluated the motion data for a much longer time, commonly in 1 second where real sprain cases the preinjury motion occurred within 40ms. Data noise observed after changing from time to frequency domain was a reason which affected the accuracy. A possible postulation was that the 500Hz sampling rate of the motion sensors was still not fast enough. Future study should investigate the effect of this and higher sampling frequency on the identification accuracy.

Jumping trials only showed a low identification accuracy, possibly casued by random motion of foot when the subject was off the ground. Polynomial fitting may not be a suitable method to identify ankle sprain motion from non-sprain common sporting motion, but similar approach could be applied to linear acceleration data collected from other anatomical landmarks. This simplified procedure aimed to obtain a potential candidate to differentiate ankle sprain motion from the non-sprain one. Reduction in used data can result in shorter processing time, which facilitates development to quick and real-time identification method. Future work to increase the accuracy by using linear acceleration data, with different order of polynomial fitting, and kinematic data from other anatomical positions should be conducted.

CONCLUSION: This study presented a method to use 500Hz sampling tri-axial accelerometer and gyrometer in classifying simulated ankle sprain motions from non-sprain common sporting motions with 91.4% accuracy. The occurrence of false alarm was 8.6%, which was smaller that, 14.3%, as reported in a previous method. Method used this time was processed in a much shorter time, reduced from 1s to 0.11s.

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