SPECTRAL ANALYSIS OF A HUMAN WALKING SEQUENCE USING MEDIAL STEREO IMAGES

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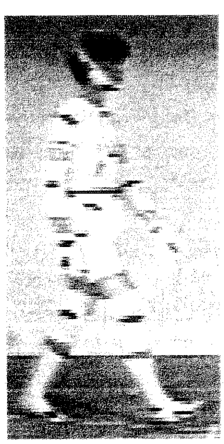
ABSTRACT

The 3-D quantitative understanding of human movements suggests powerful new knowledge in medical rehabilitation and physical fitness. Serial 3D measurement data of movement provide an important information for new medical evaluation of each person's stability in daily movement. This study presents a new approach based on spectral analysis and the utilizing 3-D videogrammetry of the walking sequence of normal persons.

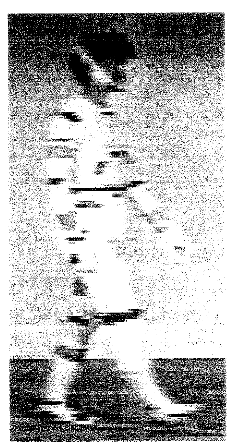
This study is based on three items. First is a synchronization system composed of two CCD video cameras, recorders and a time-generator, which solve the stereo-image matching. It recorded simultaneously a real-time control symbol on each right and left serial image. Second is a simple 3-D videogrammetric system, named "New Bird Man", for non-metric cameras using bundle adjustment with self-calibration. Third is spectral and also biomechanical analysis for finding person's walking features.

Case A



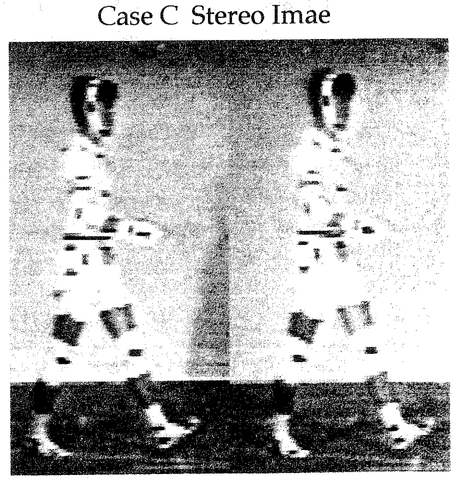
Pho. 1 Normal leg

Case B



Pho. 2 Stressed rt.leg
(experimentally fixed by orthosis)

Case C Stereo Imae



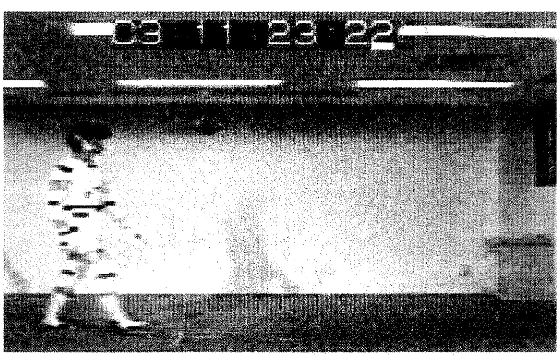
Pho. 3 Damaged lt. leg
(experienced a broken leg)

1. INTRODUCTION

The information given by biostereometrics is expected to become more important in medical rehabilitation, kinesiology and biomechanics which is an application of principles of Newton's dynamics to analyze a human movement. The developed system "New Bird Man" has a powerful biostereometrics method for CCD video camera calibration and orientation. The 3-D digital data of major joints of walking twenty persons were obtained.

Fig.1 shows a normal person walking (Case A). Fig. 2 shows a person who has experimentally fixed by orthosis (Case B). Fig. 3 shows stereo image of a person who has experienced a broken leg (Case C). The raw serial measurement data are difficult to understand about their walking features directly because of their complex fluctuations. In order to analyze the dynamical relations in human movement, this study presents a new efficient approach to spectral analysis utilizing Auto Regressive Modeling (AR-Modeling).

2. METHODS AND MATERIALS



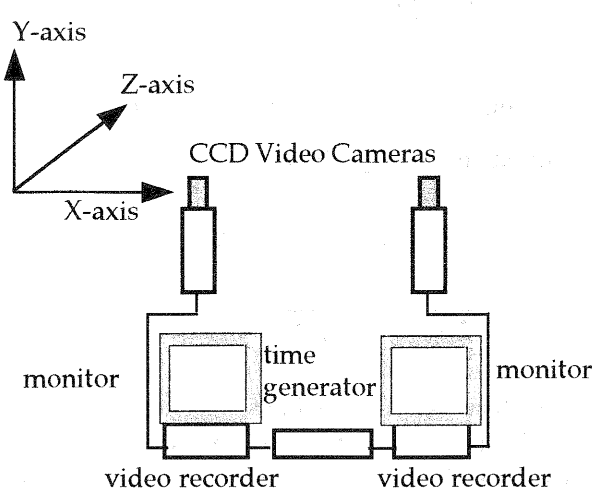


Fig. 3 Synchronized

A. Synchronized Recording System

The synchronized recording system for stereo image composed to two CCD Video camera, recorders and a time generator, which solve the stereo image matching. After recorded simultaneously a real-time control symbol, converted into time letter on each right and left serial in a ratio of thirty flames per 1 second. Five GCP (24 Ground Control Points) poles for camera calibration and orientation were set on the floor in the person's moving area, which have three points respectively.

B. New Bird Man System for Biostereometrics

Unknown 3-D data of body joint are able to analyze automatically by New Bird Man System. The flow of the system protocol is shown as follows.

[1] Coordinates Transformation for left and right Video Camera Orientation

Pixel Coordinate (512×480) of left and right GCPs were transformed to video graphic coordinates.

[2] Optimization by Least Squares Method for Estimation of Orientation Parameters

Approximate values of parameters were given to simultaneous equations by many collinearity equations made from GCPs's coordinates. That can make a estimation of parameters and reduction of a calculation time. The collinearity equations are defined as follows:

$$x = -f\frac{a_{11}(X - X_0) + a_{12}(Y - Y_0) + a_{13}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} + dx$$

$$= F(X_0, Y_0, Z_0, \omega, \varphi, \kappa, dx) \qquad (2.B.1)$$

$$y = -f\frac{a_{11}(X - X_0) + a_{12}(Y - Y_0) + a_{13}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} + dy$$

$$= F(X_0, Y_0, Z_0, \omega, \varphi, \kappa, dy) \qquad (2.B.2)$$

(Calibration Model)

$$dx = x_p + x'(d_1 r^2 + d_2 r^4 + d_3 r^6)$$

$$dy = y_p + y'(d_1 r^2 + d_2 r^4 + d_3 r^6) \qquad (2.B.3)$$

$$x' = x + x_0, y' = y + y_0, r^2 = (x'/F)^2 + (y'/F)^2$$

Orientation parameters

three rotation angles: $(\omega, \varphi, \kappa)$

projection center location: (X_0, Y_0, Z_0)

focal distance: f

principal point difference: (x_p, y_p)

lens distortion: d_1, d_2, d_3

rotation matrices: a_{ij}

C. Biomechanics of a Human Walking

The 3-D biomechanics of a human movement were discussed, center of body gravity, velocity, accerelation, torque, inertia, work etc.. In this study, metabolic energy of knee joint is discussed. The sum of metabolic energy C during waling sequence is defined as follow.

$$C = \sum_{t=1}^{n}(0.8V + 0.5) \qquad (2.C.1)$$

where V is accerelation.

D. Spectral Analysis utilizing Auto Regressive Modeling (AR modeling)

Observed data, stationary time series,

$\{x(s);s = 1,2,...,N\}$

is given, by subtracting the portion that can be expressed as a linear combination of M past values

$x(s-1),...,x(s-M)$

the series of residuals, univariate Auto Regressive Model is given.

$$\varepsilon(s) = x(s) - \sum_{i=1}^{M} a(m)x(s-m) \qquad (2.D.1)$$

Assume that the data set is given.

$\{x(s\Delta t) =,2,...,N]$

(1) Subtract the mean value, i.e.,calculatandby

$$\bar{x} = \frac{1}{N} N \sum_{s=1}^{N} x(s\Delta t) \qquad (2.D.2)$$

and defined $x(s)$

$$x(s) = x(s\Delta t) - \bar{x}(s = 1,2,...,N)$$

(2) For $l = 0,1,...,L.$ compute

$$C_{xxx}(l) = \frac{1}{N}\sum_{s=1}^{N-1} x(s+l)x(s) \qquad (2.D.3)$$

(3)Put $a_0(m) = 0(m = 1,2,..., M)$
$\sigma^2(0) = C_{xx}(0)$

(4) For $M = 0,1,..., L,$

compute $a_M(m) = (m = 1,2,...,M)$

and $\sigma^2(M)$

by the following recursive procedure:

$$a_{M+1}(M+1) = (\sigma^2(M)^{-1}(C_{xxx}(M+1) - \sum_{m=1}^{M} a_M(m)(C_{xxx}(M+1-m) \qquad (2.D.4)$$

$$a_{M+1}(m) = a_M(m) - a_{M+1}(M+1)a_{M+1}(M+1-m)$$
$$(m = 1,2,..., M) \qquad (2.D.5)$$

$$\sigma^2(M+1) = \sigma^2(M)(1 - a_{M+1}(M+1)^2) \qquad (2.D.6)$$

(5) At the same time, also compute

$$FPE(M) = (N + (M+1)(n - (M+1))^{-1}\sigma^2(M) \qquad (2.D.7)$$

and adopt $a_M(m)$ corresponding to the M that gives the minimum of $FPE(M)$
$(M = 0,1,..., L)$

(6) The estimate of the power spectral density $q_{xx}(g)$ is given by

$$\hat{q}_{xx}(g) = \frac{\sigma^2(M)}{\left|1 - \sum_{m=1}^{M} a_M(m)\exp(-i2\pi gm)\right|^2} \qquad (2.D.8)$$

by restoring the sampling interval Δt the estimate of $\hat{p}_{xx}(f;\Delta t)$ is

by $\hat{p}_{xx}(f;\Delta t) = \hat{q}_{xx}(f\Delta t)\Delta t$
$(-\frac{1}{2\Delta t} \le f \le \frac{1}{2\Delta t})$

The formula that defines the best predict is given, the power spectral density is gotten, which express the characteristics of a sequential system concisely, decomposing into periodic components.

3. RESULT AND DISCUSSION

A. Accuracy with Calibration

Table 1 Accuracy of Biosterometrics

step 1	without calibration	5.24 mm
step 2	principal point difference	5.23 mm
step 3	+ lends distortion	3. 48 mm

New Bird Man System has steps of calibration, accuracy is depended on problems of camera distortion, A/D convertor, image processing and velocity of person movement, etc., but Table 1 shows it's enough to analyze of walking.

B. Biomechanical Analysis

All persons who walked naturally under normal or stressed conditions on their legs in same distance. *Not* mechanical energy, Fig. 4 shows the change of metabolic energy (medical data) of right and left knee joint during walking in z axis.

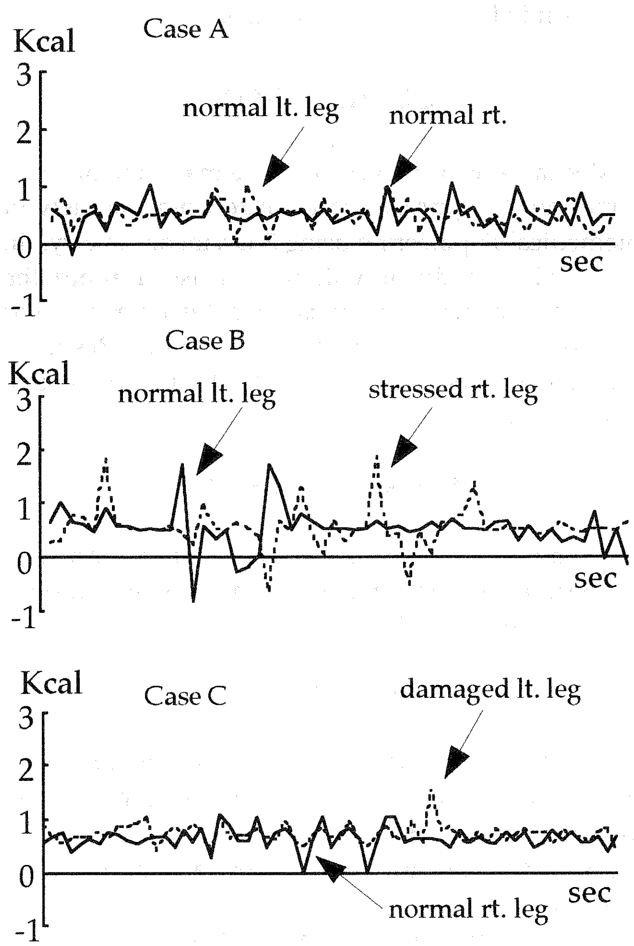
In this study, the change in z axis explains a balance of the body in right and left side.

In case A, natural normal walking, both knees of most people had approximately same changes of metabolic energy.

In case B, experimentally stressed walking, i.e., a right knee and ankle fixed by a knee-ankle-foot plastic medial orthosis, both knee had large changes, especially unfixed knee not stressed one.

In case C, a damaged leg of some persons, who had experienced a broken leg or knee ligament, had a small change, but when a damaged leg became supporting one, a large change.

Fig. 5 shows displacement of knee joint in x axis. In this study, the change in x axis, the direction of walking. Biomechanical analysis suggested the three features.



All Fig.4 Metabolic Energy (Z axis)

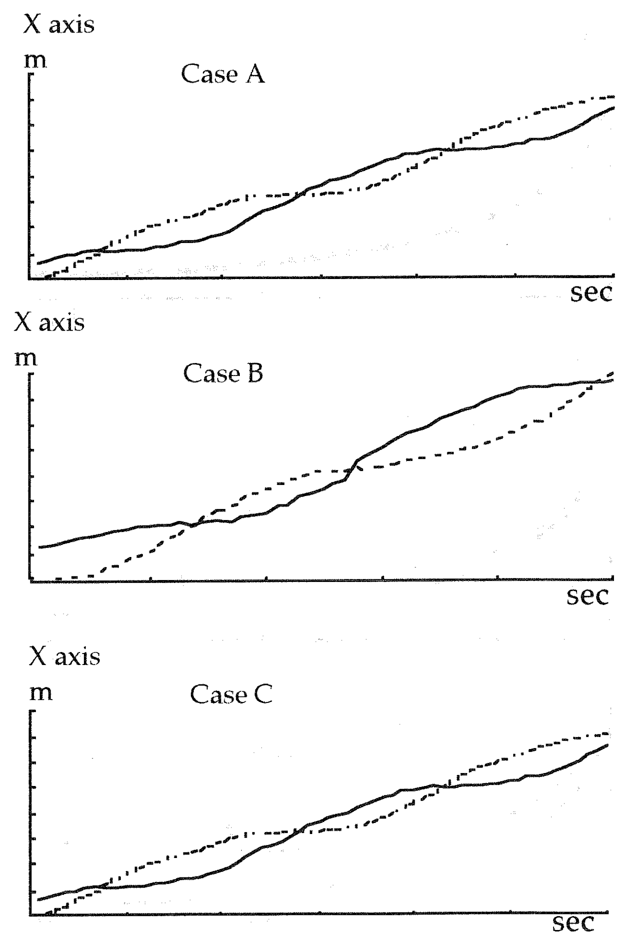


Fig. 5 Displacement of Knee (X-axis)

In cace of normal walking, case A, both knee of most people had approximately smooth sine curves, different in their slopes in spatial displacement.

In case of experimentally stressed walking, case B, i.e., a right knee and ankle fixed by a knee-ankle-foot plastic medical orthosis, the knees showed a sine-curve with small slope and amplitude and with short swinging phases of the stressed leg.

But a damaged leg of some persons (case C), who had experienced a broken leg or knee ligament had a sine curves with a small and amplitude and with short supporting phases. The normal leg, which is stressed by problem to the other leg, had a similar curve and phase as that of the problem leg.

The result of sum of metabolic energy is as follows:

Case A: normal rt leg ≒ normal lt leg
Case B: normal lt leg > stressed rt leg
Case C: normal rt leg> damaged lt leg

It is said that normal leg has burdens by influences of leg problems.

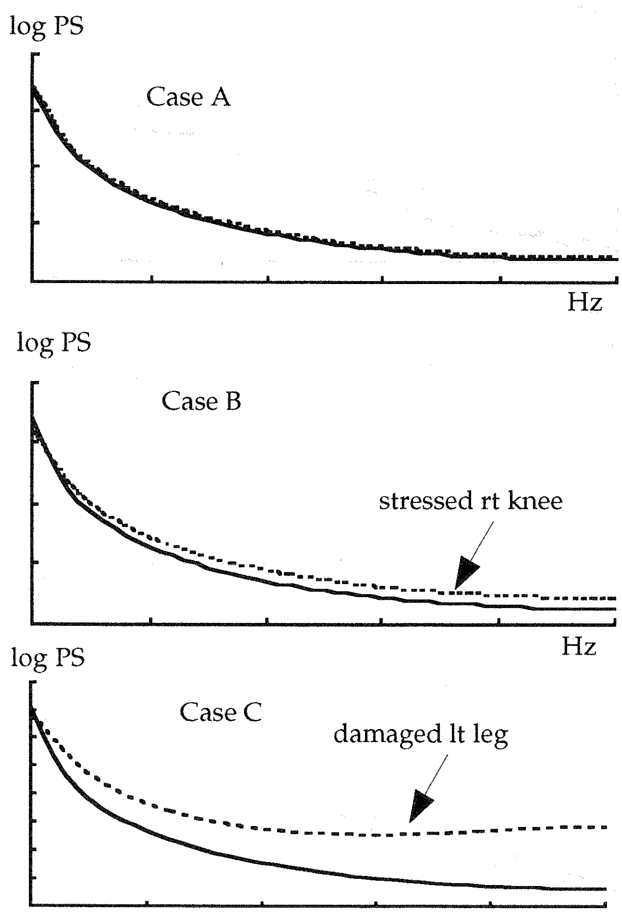


Fig. 6 Power Spectrum of Knee (X-axis)

C. Spectral Analysis

Spectral analysis suggested two features. Fig. 6 shows power spectrum of knee (X-axis), curves of log PS vs Hz indicate new information for features of walking.

In case of natural normal (Case A) and stressed walking (Case B), most people had a similar power spectrum curve for the right and left knee.

The slope of that power spectrum curve was proportioned to approximately, i.e.. power spectrum was inversely proportioned to frequency. But those (Case C), who had experienced a broken leg or knee ligament had quite different power spectrum curves for the right and left leg.

The normal leg had

$1/f^{\alpha}$ proportion,

the damaged leg had frequencies higher than the those of normal leg.

The $1/f^{\alpha}$ proportion

is depended on person's movement.

CONCLUSION

Mechanisms of movement have many factors, it is important to approach to analyze from the view of Biomedical Engineering using 3-D videogrametry. In the further study, it will be discussed about the feedback control relationship between right and left knees in walking. Analysis of Impulse Response utilizing AR modeling will indicate mechanisms of movement.

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