

## Analysis of variability in pylon transducer signals\*

D. JONES and J. P. PAUL

*Bioengineering Unit, University of Strathclyde, Glasgow*

### Abstract

A pylon transducer has been used to provide force and moment data relating to the stance phase of gait of below-knee amputees fitted with modular types of PTB prostheses.

The data has been collected and modified using digital processing systems with particular interest in quantifying shape differences in the loading information curves. Earlier tests illustrated the need for more data to provide statistical support for conclusions. However, the requirements for more data greatly increased the data handling and storage problems. A method was devised whereby those features considered significant from an information point of view could be extracted from the transducer signals and then combined. The statistical combination of features was made to allow objective comparisons of strides for a particular subject.

### Introduction

To formulate a useful locomotion study it is necessary to answer several fundamental questions:

- a) What data should be collected in the study?
- b) How will it be collected?
- c) Which part of the collected data constitutes *information* valuable to the aims of the study?

These three elements are mutually dependent. Unfortunately, the problem of extracting useful information from masses of data often seems to be treated as an "after thought" in spite of our enthusiasm in data acquisition. The evidence of this enthusiasm can be seen in many locomotion laboratories where mountains of computer output lie unused.

Data which is collected, but not essential for the success of a study is commonly referred to as "redundant". Shannon (1948) defined the concept of redundancy as: "That fraction of a message which is unnecessary and hence repetitive in the sense that if it were missing the message would still be essentially complete; or at least could be completed".

The study to be described attempts to reduce the redundancy amongst collected pylon transducer data. The nature of the required information is controlled by the aims of the study.

### Aims of the study

Previous pylon transducer studies have attempted to examine the effects of, for example, prosthetic alignment changes upon the loading signals, without first establishing that these signal patterns exhibit statistical consistency under conditions of fixed alignment.

At the University of Strathclyde the stride to stride loading signals obtained from pylon transducer tests were examined with a view to quantifying the stride to stride differences. With the signal variability established, this would form a basis for comparison once the conditions of the prosthetic experiment differ.

### The mechanism of redundancy reduction

The details of data acquisition is given later but it is convenient to note at this time that the conversion of the analogue transducer signals to their sampled data equivalents was conducted at a sample rate of 200 samples per second upon each channel.

Two simple observations of the data are helpful:

- a) Any single stance phase period will, at the

---

All correspondence to be addressed to Dr. D. Jones, Ontario Crippled Children's Centre, 350 Rumsey Road, Toronto, Ontario M4G 1R8, Canada.

---

\*Based on a paper presented at the Second World Congress, ISPO, New York, 1977.

acquisition stage, be represented by many samples of the original continuous-time signal.

- b) Successive stance phase periods may occur significantly different total times.

The first point raises worries over the amount of labour needed in a sample to sample comparison of successive stance phase periods, whilst the second point poses doubts as to whether that process would be valid.

An approach that could be used for data reduction involves the fitting of mathematical functions with orthogonal properties to the successive stride data. The best known of these methods involve polynomial expansion, Taylor series or Fourier series approximations.

Jacobs and Skorecki (1972) examined the differences in the vertical force records from a force plate, amongst subjects exhibiting both "normal" and "pathological" (in appearance) gaits. Comparisons were made by using the Fourier series spectra of the stance period data. A problem with the method arises with a loss of all phase information. Also the use of this type of representation, termed "Periodogram", can provide unreliable spectral magnitude data when only a limited signal record is available (Jenkins, 1961; Tukey, 1967; Richards, 1967; Rayner, 1971).

The examination of curvature to define a shape has received much support.

Atneave (1954) demonstrated that information sufficient for the recognition of familiar shapes was contained in a knowledge of the points of maximum absolute curvature on the boundaries of those shapes and their location and connectivity. Many others have employed these concepts (Zahn and Roskies, 1972; Tomek, 1973 and 1972).

Macfarlane and Lawrie (1972) used a function termed the "Spatial velocity" to recognize wave patterns in ECG signals. If, for example, a force vector described by its X, Y and Z components in an orthogonal reference frame changes direction by an amount SX, SY, SZ in dT seconds then the spatial velocity is given by:

$$SPV = [(SX/dT)^2 + (SY/dT)^2 + (SZ/dT)^2]^{1/2}$$

The SPV function was chosen to provide an indication of a significant event within the time history of the loading information. The supposition is that the shapes of the load signals are being examined for similarity.

## Instrumentation

The pylon transducer used has been described previously (Berme *et al*, 1975). Prior to these tests the dynamic behaviour of the transducer was examined using impulse response and Fourier Transform methods. The results for transverse and longitudinal impulse forces imply (Fig. 1) that if the activities monitored by the pylon have no significant frequency components higher than 600 Hz, then the transducer will be adequate from a dynamic viewpoint.

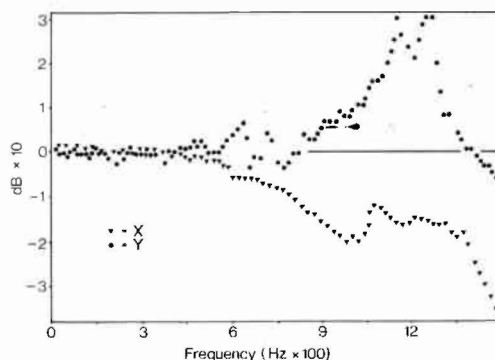


Fig. 1. Response to X and Y impulses.

Data acquisition was performed using a 12 bit A-D converter operating at 200 samples per second on each channel. A PDP-12 computer was used as a preprocessor for an ICL 1904s computer system. Prior to data reduction all data was filtered using a 4th order Butterworth-equivalent digital filter with a 3 dB down frequency of 20 Hz. Filtered data was corrected for phase distortion.

## Subject data and testing

The subject to be considered was a heavy (96 kg), active below-knee amputee with a conventional cuff type suspension PTB prosthesis. A Berkeley adjustable alignment unit was used to set up dynamic alignment to the satisfaction of the prosthetist. The alignment and shoe type were constant throughout the test series.

On each visit by the subject, six level walking periods were conducted whilst pylon transducer and knee goniometer signals were recorded. Each level walking period consisted of 20 seconds of free level walking. The subject chose his own walking rate and this was measured.

### Data reduction strategy

- 1) The number of strides needed to represent a particular walking occasion were determined.
- 2) The SPV function graph was produced for the representative strides. The ankle force vector components were used here (FXA, FYA, FZA).
- 3) The points of local extrema in the SPV function were noted. These points were considered to indicate a significant feature in the time history of the force vector. Each of the  $F_i$  "features" ( $i=1 \dots N$ ) occurs at some time  $T_i$  from the start of the data record. These occurrence times were noted (Fig. 2).
- 4) By noting the values of the FXA, FYA and FZA components at times  $T_i$  the essential characteristics were determined.

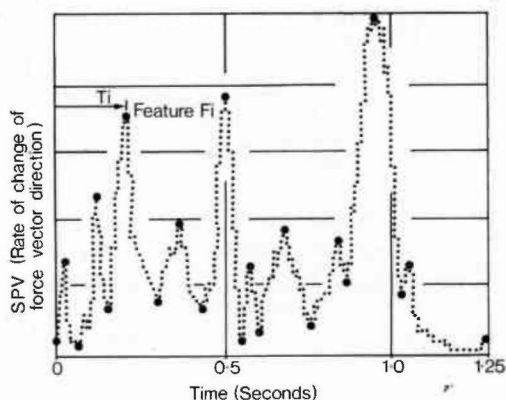


Fig. 2. SPV function example.

### Results

#### Estimate of variability for FXA component

This estimate was made so that there would be an idea of how many strides would be needed to be fairly confident of statistically representing the measured gait. The concept of sampling can be considered within the framework of the common sense notion that if all the strides collected during a walking session were absolutely identical then only the data for one stride would be needed to completely describe that session. If on the other hand all the stride data were completely dissimilar then it becomes useless to describe that walking session other than with consideration of an extremely large number of strides.

In the case under examination a range of numbers of strides ( $n=4, 8, 16$  and  $32$ ) were combined and the statistical population estimates for each of the groups were compared (Fig. 3).

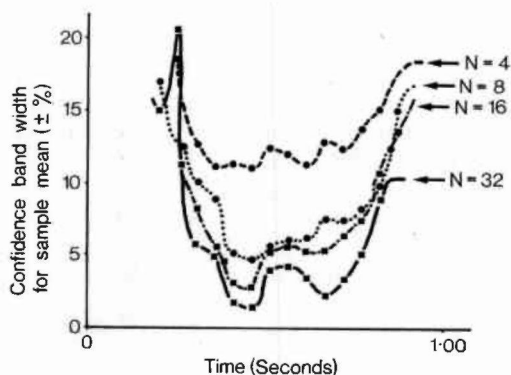


Fig. 3. How  $n$  affects the confidence of  $\bar{X}$  as an approximation to  $\mu$ .

Not surprisingly as  $n$  increased the confidence of  $\bar{X}$  (the particular sample mean) as an approximation to  $\mu$  (the time population mean) improved. However, the amount of work required also increased with  $n$  without a proportionate increase in information. As a compromise, for the level walking tests, 8 stance periods were considered sufficient to describe an individual walking session.

#### Stride variations in force vector within a level walking session

Eight consecutive strides were extracted from a level walk conducted by the subject. Each stride was examined, processed and a set of features produced for each. Observation of the SPV function for these strides provided 16 features. The times of the feature indicators from the start of the stance periods were recorded, along with the values of the force components FXA, FYA, FZA at each feature time.

The eight sets of sixteen "critical" values were combined for these components. Figure 4 shows these components synthesized from their feature values, their time occurrences and their 95% confidence intervals from the mean values.

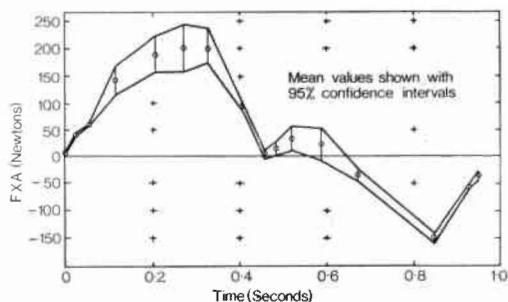


Fig. 4a. Synthesized for eight strides with the features of FXA (16 features used).

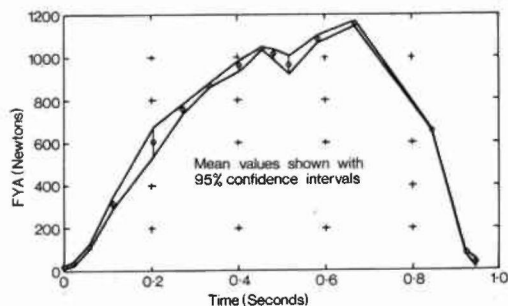


Fig. 4b. Synthesized for eight strides with the features of FYA (16 features used).

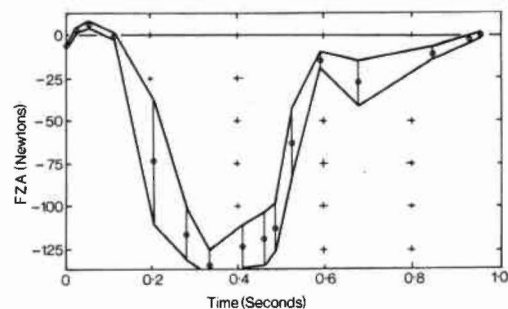


Fig. 4c. Synthesized for eight strides with the features of FZA (16 features used).

A representation of the magnitude confidence intervals versus feature number is given in Figure 5. This shows rather more clearly the places and values of the confidence limits for each of FXA, FYA and FZA. Considering the FXA set, the widest confidence interval is seen at the 6th feature time and has a value of  $\pm 42\text{N}$ . From an initial low variability close to heel strike the variability increases rapidly between the 3rd and 4th features and then decreases to

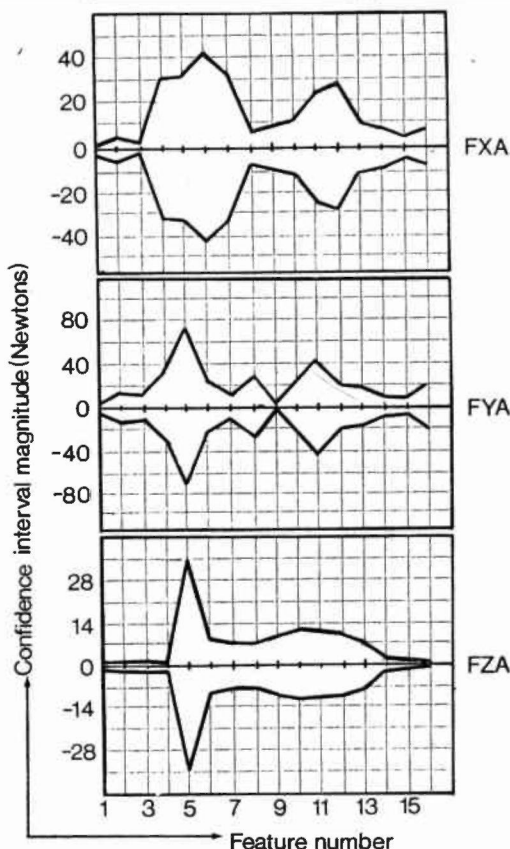


Fig. 5. Confidence interval variation during stance period.

less than  $\pm 10\text{N}$  at midstance. During the roll over period the variability increases to a peak at feature 12 of  $\pm 28\text{N}$  before decreasing again toward toe off.

For the FYA set the peak variability at feature time 5 was such as to allow a confidence interval of  $\pm 70\text{N}$  about the sample mean. The characteristic twin peaks were present with confidence intervals of less than  $\pm 20\text{N}$  at each peak. The trough between these peaks showed evidence of a local region of higher variability with a confidence interval of  $\pm 40\text{N}$ .

The FZA set exhibits one strong peak of  $\pm 35\text{N}$  interval width at feature time 5, rising from a region of low variability at feature time 4. The rest of the period shows a fairly even variability distribution without the local high spots of FXA and FYA.

Overall the region of features 5 and 6 displays the largest stride to stride variability.

### Variations from walking session to walking session

Figure 5 may now be considered to be related to the variability of the pylon transducer data during a single walking session. For that session, at each feature  $F_i$ , the population mean  $\mu_1$  is estimated by the calculated mean  $\bar{x}$  with a

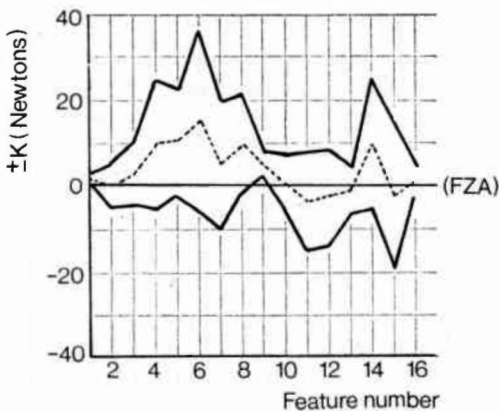
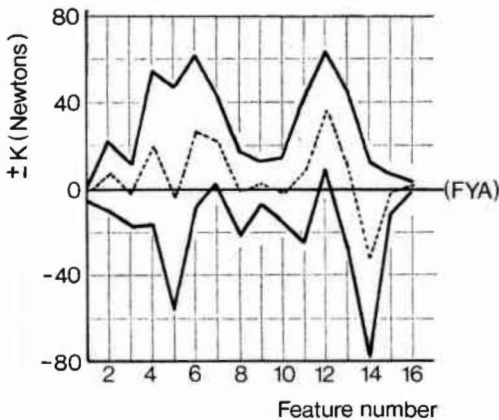
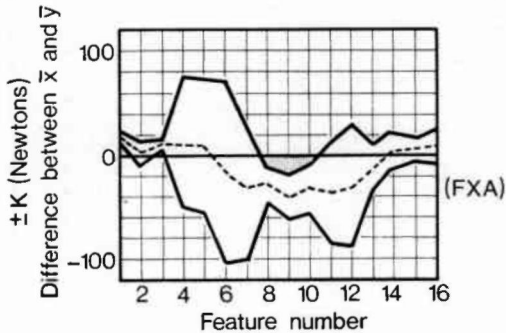


Fig. 6. Comparison between two level walking sessions.

confidence interval computed from the sample variance  $SX^2$  (which itself is an estimate of the population variance  $OX^2$ ).

Considering a 2nd walking session with again the averaging being computed over 8 stance phase periods. This time at the  $F_i$  values, the population mean  $\mu_2$  is estimated by a calculated mean of  $\bar{y}$  with a variance estimate of  $SY^2$  (being an estimate of the true variance  $\sigma y^2$ ).

A test may then be made for the assumption that the data from these two level walking sessions belong to the same statistical population (that is, that the difference between  $\mu_1$  and  $\mu_2$  at the  $F_i$  is insignificant).

Taking  $\bar{x}$  and  $\bar{y}$  as the estimates for the two population means:

$\bar{x} - \bar{y}$  will be Normally Distributed with a mean  $\mu_1 - \mu_2$  and a standard deviation of  $\sqrt{(SX^2 + SY^2)/8}$ .

The 95% confidence intervals are given by:

$$(\bar{x} - \bar{y}) \pm 1.96 \sqrt{(SX^2 + SY^2)/8} = (\bar{x} - \bar{y}) \pm K$$

If these limits do not include zero then the difference is said to be significant at the 5% level.

Figure 6 shows the result of the comparison of two walking sessions conducted with the subject, expressed as a display of  $\pm K$  as a function of feature number. Those areas shaded black correspond to the areas of significant differences between the information upon the two walking sessions.

### Summary

The variability in pylon dynamometer data acquired during level walking tests has been examined. The information upon variability has been considered to lie within the shapes of the loading signals. The extraction of this information from the data was performed as indicated by the local extrema of a spatial velocity curve. For the study example given no significant differences could be found for the subject's gait between time separated walking sessions (with constant experimental conditions). Data reduction has provided a statistical template representing the subject's gait on a particular occasion. This template may then be used in comparison with templates produced under different experimental conditions (that is, alignment or footwear changes).

## REFERENCES

- ATTNEAVE, F. (1954). Some informational aspects of visual perceptional. *Psychology Review*, **61:3**, 183-193.
- BERME, N. *et al* (1975). A shorter pylon transducer for measurement of prosthetic forces and moments during amputee gait. (Submitted for publication) *Engineering in Medicine*. The Institute of Mechanical Engineers.
- JACOBS, N. A. and SKORECKI, J. (1972). Analysis of the vertical component of force in normal and pathological gait. *J. Biomech.*, **5**, 11-34.
- JENKINS, G. M. (1961). General considerations in the analysis of Spectra. *Technometrics*, **3:2**, 133-166.
- LAWRIE, T. D. V., and MACFARLANE, P. W. (1972). Routine automated electrocardiogram interpretation. *Biomed. Eng.* May, 176-180.
- RAYNER, J. N. (1971). An introduction to spectral analysis. Pion Ltd., London.
- RICHARDS, P. I. (1967). Computing reliable power spectra. *IEEE Spectrum*, 83-90.
- SHANNON, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, **27**, 379.
- TOMEK, I. (1972). A clustering technique in the classification of almost periodic waveforms. *Computers in Biomedical Research*, **5**, 621-628.
- TOMEK, I. (1973). Two quantitative measure of similarity of one class of waveform. *Computers in Biomedical Research*, **6**, 499-508.
- TUKEY, J. W. (1967) An introduction to the calculations of numerical spectrum analysis. In *Spectral Analysis of Time Series*, 24-46. Ed. Harris, B. Wiley and Sons.
- ZAHN, C. T. and ROSKIES, R. Z. (1972). Fourier descriptors for plane closed curves. *IEEE Transactions on Computers*, **C21:3**, 269-281.