Biomechanics Toolbar

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INTRODUCTION

Processing data from human movement analysis can be a daunting task for undergraduate students, who are often for the first time faced with this in their final year research projects. Particularly in those study programmes that typically contain limited computing and mathematical contents such as physical education, physical and occupational therapy, sport science, biology, etc, this can be a challenge. Particularly in cases where first the use of a specific piece of software needs to be learnt this can lead to disillusion and in the worst case students will strictly follow the teacher's guidelines for data processing without understanding what is really happening to their data. It can be equally daunting for academic staff to prevent the latter behaviour and teach the necessary skills to these students in anticipation of research projects, particularly if data processing tools are only available in software packages not commonly used outside of human movement analysis. This document is intended to overcome the software threshold and to provide an educational package with basic data processing tools that can be run within an environment that is familiar to the student. Students can learn by doing, which is facilitated by the Biomechanics Toolbar.

The Biomechanics Toolbar is a custom toolbar for use in Microsoft Excel which functions in a similar way as other toolbars in Microsoft software. It is built in line with the structure of this document, based on the analysis of data as often encountered in undergraduate as well as postgraduate research. It has been developed for users that can already work with Microsoft Excel and provides a platform for those who have or wish to gain a basic understanding of biomechanical data processing. Using the Toolbar in conjunction with this document, it can be a useful starting point for teaching basic data processing techniques, and the strengths and limitations of those techniques. Most tools are based on techniques described in the standard textbook of Winter (2^{nd}-4^{th} edition), and otherwise on references that can be read and understood, even at undergraduate level of movement analysis programmes (Nyquist classic paper as only exception).

Functions embedded in the Biomechanics Toolbar will be referred to as tools. All tools use a **"select – process – paste"** concept, designed to facilitate maximized flexibility in data management within Excel. The user first selects the data that needs to be processed, then runs the appropriate tool from the Biomechanics Toolbar to process the data, and finally the data is made available from the clipboard so that it can be pasted anywhere within Microsoft Excel.

IMPORTANT: Except for the residual analysis tool, all tools support the selection of multiple columns, as long as all columns initiate in the top row of the selection and the selection does not contain empty columns. Except for the gap filling tool, gaps in the data are not allowed. The toolbar is based on macros, and therefore to be able to install, use, or uninstall the toolbar, macros need to be enabled when prompted. When prompted to keep a large amount of data on the clipboard after a tool has run, this should be confirmed so that the output data retains on the clipboard for pasting. DO NOT CANCEL in this prompt. The remainder of this document is an outline of the individual tools, a description of the techniques on which they are based, their functionality, and where necessary an indication of their applicability.

GENERAL

Gap filling

DESCRIPTION:

Data collected with marker-based cinematography often has small gaps due to markers disappearing from the cameras' views. Gaps in the data can jeopardize further processes such as data filtering or time normalisation, and even with one single sample missing this can cause of doubts with students on how to proceed. Gap filling data series can be established through many interpolation techniques such as spline or polynomial fitting, each of which try to optimise the similarity between the simulated data in the gap and the likely marker position. The most basic one, however, is linear interpolation, in which the two values at the edge of the gap are simply connected by a straight line for the missing samples. The concept of this technique is described in Winter (2009) under the paragraph on normalisation of time bases to 100%.

FUNCTIONALITY:

Gaps are indicated by empty cells rather than "NaN'" or other indications. The default maximum size of any gap is 10 samples, but there is the option to change this. There is also the option to visually inspect the gap filled data. If visual inspection is confirmed, a graph is shown for each data series overlaying interpolated data with original data to aid in justification of the linear interpolation. If it is known that any gaps are very small, then visual inspection can be cancelled.

Time normalisation

DESCRIPTION:

Particularly when data on cyclic movements is collected, one often wishes to present data from individual cycles on a time scale that is normalised from zero to 100 percent of the movement cycle. Using linear interpolation between nearest data samples, the tool reduces the length of the data to 101 samples. If the length of the shortest selected data series is less than 100 samples, reduction is done to 51 samples, and if less than 50 samples, reduction is done to 21 data points. The tool uses 101 samples rather than 100 to provide data points ranging from zero to 100, including a data point on time zero. This is common practice in movement analysis.

FUNCTIONALITY:

The minimal number of values in any column of the selection must be higher than 20.

Frequency reduction

DESCRIPTION:

Visualisation of data retrieved from different sources can often benefit from using a secondary Y-axis to overcome baseline and/or magnitude differences between the signals. However, besides baseline/magnitude differences, data can also be available at different sampling frequencies. For example kinematics is often sampled at a frequency of 50 or 100 Hz, whereas forces or EMG come at frequencies of 1000 or 2000 Hz. Presenting these data in the same graph can be challenging in Microsoft Excel. With the frequency reduction tool the signal with highest frequency can be reduced to the lower sampling frequency of the other signal. The technique used for this is linear interpolation between the two data points nearest to the new data sample (Winter, 2009).

FUNCTIONALITY:

The user is asked for the input frequency, i.e. the actual sampling frequency, and subsequently for the output frequency. The input frequency of the dataset must be higher than the output frequency, only allowing for a reduction of frequency. It is important to highlight that this reduction facilitates visualisation, and should be preceded by any filtering techniques.

Endpoint synchronisation

DESCRIPTION:

It is in movement analysis sometimes not desirable to normalise time to 100% in order to maintain the mechanical characteristics of the signal. For example, visualising the surface underneath a force curve represents the impulse and can only be visually inspected on an absolute time scale. The standing vertical jump is a movement commonly used for undergraduate teaching of force data analysis (Linthorne, 2001). With take off being a key event at the end of the push off phase, synchronising data from different trials at the end row of data without loosing the mechanical characteristics through time normalisation can help in interpreting data. The endpoint synchronisation tool reduces the effort of shifting all columns towards the final data point to a single mouse click.

FUNCTIONALITY:

The tool has an option to extrapolate the first data point as a constant prior to the actual data. This option is conceptually only valid if the signal is expected to be constant prior to the start of the actually recorded data. This is for example the case in force data of a vertical jump from stance, as the force prior to the actual jump is expected to remain body weight. Using this option allows smoother average data graphs at the start when small inter-trial variations in data length are accompanied with inter-trial variations in body weight. The extrapolation is not desirable for use with large variations in data length, as it could lead to wrong interpretation of the data.

Invert data

DESCRIPTION:

With horizontal forces students often wish to negate the values of their data, for example in cases where forward forces recorded during locomotion were measured as negative forces. This tool simply changes positive to negative values and vice versa. It is also useful when coordinate systems of devices differ, for example, as often found for those of force platform and motion system.

EMG

Butterworth Low Pass Filter

DESCRIPTION:

Filtering of data is not a trivial issue, and involves difficult choices. First, the type of filter needs to be selected from a nearly endless variety of filters, each with their own strengths and weaknesses. These can be hard or impossible to understand for undergraduate and even postgraduate students in movement analysis. The Butterworth digital filter is commonly used in movement analysis as it can be understood via the relatively simple formulae of its coefficients (Winter 2009) and its positive responsiveness for derivatives of kinematic data (Robertson & Dowling, 2003). To improve validity of filtered data at start and end, the data is first padded with extra samples at start and end using the reflection method for padding point extrapolation (Smith, 1989). The length of the padded data is one second (Howarth & Callaghan, 2009). The filter is the Butterworth fourth order zero lag filter as described in Winter (2009). This tool is the same as the one for kinematics.
After band pass filtering and rectification of EMG (see below), EMG data can also be low pass filtered with a low cut off (e.g. 10 Hz). This is often referred to as linear envelope. See the chapter on processing of the electromyogram in Winter (2009) to gain some basic insight into the application of this linear envelope, the common confusion with integration of EMG, and the appropriate choice of low pass filter.

FUNCTIONALITY:

The user is asked to insert sampling frequency and filter cut off frequency. Default frequencies for EMG are 1000 Hz sampling and 400 Hz cut off. The filter cut off frequency can maximally be half the sampling frequency according to the Nyquist theorem (Nyquist, 2002). The user has the option to visualise the filtered over unfiltered data, but this is only shown for the data of the first column of the selection.

Critically Damped High Pass Filter

DESCRIPTION:

Particularly EMG is often prone to low frequency oscillations due primarily to movement artefacts in the 5-10 Hz frequency domain, which one wishes to remove prior to analysis of the signal. This tool filters a dataset removing frequencies below the chosen cut off frequency, and keeping high frequencies (not strictly true; see Winter (2009) under the paragraphs on analogue and digital filtering of signals). The design of the filter is based on the coefficients of the low pass Butterworth filter as described in Murphy and Robertson (1994). The reflection method is used for padding point extrapolation (Smith, 1989), adding 15 samples to start and end.

FUNCTIONALITY:

The user is asked to insert sampling frequency and filter cut off frequency. Default frequencies for EMG high pass filtering were set at 1000 Hz sampling and 5 Hz cut off. The filter cut off frequency should be less than half the sampling frequency (Nyquist, 2002). The user has the option to visualise the filtered over unfiltered data, but this is only shown for the data of the first column of the selection.

Band Pass Filter

DESCRIPTION:

For EMG, a common term for filtering is band pass. For students, understanding this concept is relatively easy, but deciding on frequencies is difficult. Considering that the toolbar contains a low pass and high pass filter, students can learn to understand the individual effects on EMG data, and eventually the combined effect when performed sequentially as a band pass filter. In this tool, data is first high pass and then low pass filtered, using the filters available in the toolbar. The resulting signal is therefore the same as when performing the individual filters sequentially.

FUNCTIONALITY:

The user is asked to insert sampling frequency, high pass cut off frequency, and then low pass cut off frequency. Default filter cut off frequencies were set at 5 Hz high pass and 400 Hz low pass. These values were chosen as EMG signals are expected to primarily occur at frequencies between 5-10 Hz and 400-450 Hz (Merletti, 2006). Default sampling frequency was set at 1000 Hz as the Nyquist theorem dictates sampling of at least twice the highest cutoff frequency (Nyquist, 2002). Vice versa, the cut off frequencies need to be less than half the sampling frequency. The user also has the option to visualise the filtered over unfiltered data, but this is only shown for the data of the first column in the selection.

Full wave rectification

DESCRIPTION:

Raw EMG data has positive and negative peaks, so that the average does not represent the magnitude of electrical activity. A common technique to make the average magnitude meaningful is to rectify EMG data by changing negative values in a dataset into equal but positive data. This is called full wave rectification (Winter, 2009), whereas half wave rectification makes negative values zero. The latter was inherited from limitations of early analogue data manipulation techniques, and is no longer commonly used. This tool performs a full wave rectification on the data, basically taking the absolute value of each sample.

KINEMATICS - KINETICS

Residual Analysis

DESCRIPTION:

Choosing the best cut off frequency for filtering kinematic or kinetic data can be done in several ways, with the residual analysis being favoured over a harmonic analysis as the characteristics of the filter that is used are reflected in the decision making process (see paragraph on choice of cut off frequency in Winter, 2009). The residual analysis tool uses the Butterworth low pass filter and presents the averaged differences between filtered and unfiltered signal for cut off frequencies ranging from 1 to one quarter of the sampling frequency, at an interval of 1 Hz.

FUNCTIONALITY:

Importantly, the residual analysis only works for a selection of one column. This choice was made to highlight the explorative nature of a residual analysis. The user is first prompted to insert sampling frequency, default set at 100 Hz. Then the user is asked for the maximal frequency to which the residual analysis has to be calculated. Default is one quarter of the sampling frequency. The user can change this value to any value less than half the sampling frequency (Nyquist, 2002). The output of the residual analysis is a single column with the calculated residuals for frequencies of 1, 2, 3,… to the maximally calculated frequency.

Butterworth Low Pass Filter

DESCRIPTION:

Filtering of data is not a trivial issue, and involves difficult choices. First, the type of filter needs to be selected from a nearly endless variety of filters, each with their own strengths and weaknesses, but which are hard or impossible to understand for undergraduate and even postgraduate students. The Butterworth digital filter is commonly used in movement analysis as it can be understood via the relatively simple formulae of its coefficients (Winter 2009) and its positive responsiveness for derivatives of kinematic data (Robertson & Dowling, 2003). To improve validity of filtered data at start and end, the data is first padded with extra samples at start and end using the easily understood reflection method for padding point extrapolation (Smith, 1989). The length of the padded data is one second of samples (Howarth & Callaghan, 2009). The filter is the Butterworth fourth order zero lag filter as described in Winter (2009). This tool is the same as the one for EMG processing, but default values are set for kinematic data.

FUNCTIONALITY:

The user is asked to insert sampling frequency and filter cut off frequency. Default sampling frequency for kinematics is set at 100 Hz. The filter cut off frequency has to be less than half the sampling frequency (Nyquist, 2002). The user has the option to visualise the filtered over unfiltered data, but this is only shown for the data of the first column of the selection.

Differentiation

DESCRIPTION:

Numerical differentiation of a signal over time is a basic skill for processing kinematic data. This tool calculates the finite difference as described in Winter (2009), avoiding a time shift by calculating the finite difference over two time intervals, i.e. based on previous and next sample.

FUNCTIONALITY:

The user is asked to insert sampling frequency.

Integration

DESCRIPTION:

Numerical integration could be considered the opposite to numerical differentiation. This tool calculates the time integrated by using the trapezoidal rule.

FUNCTIONALITY:

The user is asked for sampling frequency, and also for the integration constant. The integration constant is set to zero, but can be changed if the initial value of the output signal is known.

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